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Is attention unitary or divisible by modality?

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IS ATTENTION UNITARY OR DIVISIBLE BY MODALITY?

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ABSTRACT

Using the attentional network task (ANT) developed by Fan et al. (2002) and a modification of this task, the development of selective attention in a bimodal (auditory and visual) task is measured and compared to the results and development of the visual version of the task. The theoretical purpose of the study was to determine whether the attentional mechanism involved in this task is organized as a single mechanism or into modality-specific mechanisms. It was shown that adults needed specific instructions to efficiently use the auditory spatial warning cues but instructions were not required for efficient use of visual spatial warning cues. Overall, the adult results suggested that a “translational step” was utilized to change the auditory cue into a visual expectation, which supported a unitary mechanism. Development of bimodal selective attention was measured with three groups of children (Ages 6, 8, and 10) and these results also indicated support for a single attentional mechanism. Some questions appeared about the validity of the use of the ANT task with children.

INTRODUCTION

Pashler states “People are always (or almost always) subject to stimulation in different sensory modalities. In light of that fact, it is surprising that the relation between selection in one modality and selection in another has been relatively little investigated” (1998, p. 88). Bimodal selective attention is relevant for research that can inform our understanding of performance on tasks such as listening to instructions in the classroom, taking notes during a lecture, and even receiving directions while driving. One of the most well-known models of working memory is Baddeley's model (2000), which has separate mechanisms for the visual and auditory modality storage. Many have suggested that because there are modality specific storage mechanisms then there must also be modality specific attentional mechanisms in addition to general mechanisms (Bedi, Halperin, & Sharma, 1994; Guttentag, 1985; Gomes, Molholm, Christodoulou, Ritter, & Cowan, 2000). One approach to investigating these alternatives is to compare the developmental trends of performance to the adult patterns. For example, some research has shown that young children have a preference for stimuli presented in the auditory modality over that presented in the visual modality but that this preference changes sometime before adulthood (Robinson & Sloutsky, 2004; Sloutsky & Napolitano, 2003). There is also literature focused on the developmental improvements in performance in visual tasks in the presence of distracting sounds with increasing age (Elliott, 2002; Hanauer & Brooks, 2003).

In this study, the mechanism of attention was investigated with the Attentional Network Task (ANT), first introduced by Fan et al. (2002). This task is built around the original flanker task of conflict (Eriksen & Eriksen, 1974) and incorporates four types of warning cues. The target set for the ANT consists of five horizontal lines and the center line always has a right or left arrow attached to it. The other four lines, also called flankers, change to match the condition. The flankers will appear as horizontal lines (neutral condition), have arrows connected to them which point in the same direction as the target arrow (congruent condition), or have arrows connected to them which point in the opposite direction as the target arrow (incongruent condition). The warning cue variable appears before the target set appears and consists of one or two asterisks intended to warn the participant that a target set is about to appear. The warning cue has four different types: a single cue which appears over the central fixation cross (central cue), a single cue which appears above or below the fixation cross in the same location as the target set will soon appear (spatial cue), two asterisks which appear in both locations in which target sets appear (double cue) or no asterisks appear at all (no warning cue).

The ANT is unique in that it is capable of measuring the orienting, alerting, and executive control aspects of attention. The orienting function has been localized in the superior parietal lobe, the alerting function has been localized in the right hemisphere in the frontal and parietal lobes, and the executive control function was localized in the lateral prefrontal cortex and the anterior cingulate of the brain (Fan & Posner, 2004). Benedict et al. (1998) found similar evidence that supports the localization of the executive control and alerting mechanisms involved in the ANT.

The three networks of attention are assessed in the ANT by taking two of the conditions and finding the difference. For example, the score for alerting is determined by subtracting the double cue condition from the no cue condition, and the score for orienting is determined by subtracting the spatial cue condition from the central cue condition. The score for executive control is found by subtracting the congruent flanker conditions from the incongruent conditions. It was originally found that the networks were independent of one another in a correlational analysis (Fan et al., 2002) but further studies have found correlations between the orienting and conflict scores (Fossella et al., 2002) or correlations have occurred with small changes to the paradigm (Callejas, Lupianez, & Tudela, 2004). This task has multiple applications in behavioral, neurological, and developmental research, and future work with this task should continue to explore the possibilities.

Developmentally, each of the three networks shows an independent progression in the brain. Rueda et al. (2004) found that the alerting network has a long developmental path with children ages 6-9 not differing a great deal from each other but performing significantly less efficiently than adults. The orienting network was shown to develop primarily in early childhood because scores did not differ significantly between the youngest group, age 6, and the adults. The executive control network showed developmental improvement until approximately 7 years of age and then leveled off.

The current study sought to analyze how the presence of one modality of stimuli affected performance in a different modality so a new task was created to compare to performance in the adult version of the ANT (Fan et al., 2002) and the child version of the ANT (Reuda et al., 2004) to a bimodal version. This new bimodal task was created by removing the visual warning cues, which were asterisks, from the original version of the ANT and replacing them with tones that represent the same conditions. The goal of this manipulation was to provide a way of studying the nature and developmental path of the attentional mechanisms involved. Previous studies of attention (to be discussed later in introduction) varied greatly in methodology and by the type of attention studied, so the overall picture was missing information of the development of attentional mechanism(s) by manipulating the modality of only one consistent variable.

Three possible hypotheses were proposed to address the question of the architecture of attention. Is attention represented by a single mechanism or is it divided into two or more separate mechanisms, which individually process all sensory information from a single modality? The three hypotheses were named from the possible patterns of performance on the ANT, but each one supports a different configuration of the attentional system. These hypotheses will be discussed in terms of the type of mechanism that would be seen in behavioral data, the previous literature that suggests that this mechanism is plausible, and the predictions for results from this study that would support the hypothesis. The order of the discussion of the hypotheses will be the Beneficial Effect Hypothesis, the Detrimental Effect Hypothesis, and the Overall Slowing Hypothesis.

Beneficial Effect Hypothesis

This hypothesis proposes two attentional mechanisms, one that processes only auditory stimuli and one that processes only visual stimuli. Furthermore, these mechanisms develop at different rates. This hypothesis would predict superior performance in a bimodal task if capacity is not shared between the mechanisms or if the auditory attentional mechanism has greater maturity than the visual mechanism. The result would be quicker processing of the auditory warning cue, which would then allow for more capacity to process the visual target type and then respond. The literature that supports this hypothesis has come from three very different types of research, but originated with the working memory model proposed by Baddeley and Hitch (1974). In Baddeley's (2000) model, he limits all attention to the control of the central executive but he remains vague about the issue of modality specificity or generality. The model proposes a division of the storage mechanisms by modality but it remains unclear whether the central executive could also be separated by modality. Further evidence for a separation of the attentional mechanisms by modality can be seen in the automatic attention literature, the developmental reactivity to modality specific stimuli, and the neuroimaging research.

One debate in the literature involves a supramodal mechanism or modality-specific mechanisms of the endogenous, automatic selective attention (Ward, 1994; Spence & Driver, 1996; Turatto, Benso, Galfano, & Umilta, 2002). The supramodal hypothesis suggests that only one attentional mechanism controls all modalities, and therefore, when stimuli are presented in two modalities, the participant has limited capacity and performance suffers. This hypothesis also predicts that one would involuntarily attend to two modalities simultaneously. The modality-specific hypothesis predicts that one can choose to attend to a specific modality of stimuli and ignore another simultaneous and different modality stimulus. But in the case of two, equally important different modality stimuli, the participant is capable of attending to both equally. The focus of these hypotheses is endogenous and automatic attention, which is the type of attention that does not require focus or intention on the part of the participant. It can be implemented without eye or head movements, and is directed simply by the intensity and lack of expectancies for the stimulus.

An example of the most common paradigm in this line of research is demonstrated by Ward, McDonald, and Lin (2000). Participants performed the experiment in a darkened room with three spatial positions represented by LED lights and speakers in those positions. After receiving a valid or invalid warning in either auditory or visual modality or both or neither (within-subjects), participants would press a button as soon as they noticed the auditory or visual target stimulus (between-subjects). The trials were either valid (50% of the time) or invalid (50% of the time) and participants were instructed that the cues were not predictive. Another variable that was presented within-subjects was of the SOA between presentation of cue and target. The four SOA conditions were 100, 200, 550, or 1050 ms. The reason for this variation was to look at the time course for visual or auditory alerting to similar or different targets. While they found that auditory cues created very little cueing effect (benefit of faster responding) for visual targets, they did find that a visual cue in the 100 ms SOA condition did produce a significant cue effect for auditory targets.

With the variance of validity of trial and SOA timing, the authors concluded that this single significant cueing effect was an automatic, and modality specific effect. In other words, participants' were drawn to the visual cue unintentionally which allowed for a faster response for a valid, auditory target after a very short SOA. This conclusion supports the modality-specific mechanism for attention because it appeared that participants ignored auditory cues, and in some cases visual cues, after being told that they were uninformative.

Sloutsky and Napolitano (2003) used a same/different recognition task to test if 4-year-old children could distinguish old versus new stimuli when combinations of the auditory and visual modality were tested. For example, an old visual stimulus could be paired with a new auditory stimulus. The visual stimuli were landscape images and the auditory stimuli were three computerized tones in a random pattern. Their results showed that the children were almost completely dependent on the auditory stimuli, whereas the adults depended solely on the visual stimuli. Through the use of calibration experiments, they could determine that the children could effectively process both stimuli independently. However, they could not clearly determine the basis of the children's preference. One hypothesis was an inability to process both stimuli, leading to a dependence on the preferred stimulus. The other hypothesis was a strategy decision made by the children due to greater familiarity or importance placed on auditory stimuli.

To follow up on the unanswered questions in the first study, Robinson and Sloutsky (2004) used a very similar paradigm with some different stimuli. They utilized geometric shapes (three shapes connected in one experiment and a single shape in another experiment) for the visual stimuli in this experiment because of concerns that the landscapes in the previous study were too complex. The sounds were also changed so that a buzzer sound and a laser sound were used instead of tones. They changed the task that trained the participants to recognize two sets of stimuli in which each set includes one auditory stimulus and one visual stimulus. One set is presented in each trial and the participant's job was to pick the side of the screen which had been paired with that stimulus that would also reveal a cartoon animal.

When using the three shapes, they found that the children fell into two categories: those that mainly depended on the auditory stimulus for their predictions, and those children whose predictions were not dependent on either type of stimulus but mixed between the two. The adults once again showed a strong preference for the visual stimulus and based decisions on that stimulus. However, when only one geometric shape was utilized, half of the children fell into the mixed category and a smaller but still large percentage were mainly dependent on the visual stimuli for their decisions. Robinson and Sloutsky (2004) even trained 4-year-olds and adults the same way and then removed the stimulus that the group had mostly depended on in the previous experiment and found that the 4-year-olds were unable to respond correctly with the visual stimuli in the 3-shape condition and unable to respond correctly to the auditory stimuli in the 1-shape condition. Adults were able to adapt in both cases, although performance was better in the 1-shape condition than the 3-shape condition. This unusual change in preferences and ability to perform could indicate that the simpler stimulus was usually processed by the children instead of the more complex stimulus which was ignored. The adults, however, did seem to be capable of processing both types of stimuli when presented together but the complexity of their preferred stimuli could have affected how much they attended to the other stimulus. In a separate experiment, they asked the 4-year-olds to focus on the previously unattended stimuli (the visual stimulus in the 3 shape condition and the auditory stimulus in the 1 shape condition) and they found that both groups did improve but more than half of each group was still dependent on the preferred modality.

To summarize, the series of experiments from both Sloutsky and Napolitano (2003) and Robinson and Sloutsky (2004) have several important implications for the understanding of our ability to process information from the two modalities. First, young children are more likely to process auditory stimuli than visual stimuli if both are equally complex. Second, children will switch preferences if the visual stimulus is less complex and more familiar than the auditory stimulus. The majority of the time, children will only process one of two stimuli when presented simultaneously as in these tasks. Also, adults are capable of processing both types of stimuli and can use an auditory stimulus when the preferred visual stimulus is unavailable. Adults' performance does suffer when the preferred stimulus is complex and they are forced to respond using the non-preferred stimulus.

Bedi, Halperin, and Sharma (1994), using visual tasks and auditory tasks, demonstrated the distinctive individual distractibility of children. The auditory task had two conditions, no distractions and distractions, and consisted of a female's voice presenting sequences of 1-8 numbers which were used as a digit span measure, and a male's voice speaking letters in between the numbers of the digit span only during the distraction condition. The visual task had three conditions: no distractions, 2 distractions, and five distractions, and the goal was to press the space bar when a blue rectangle appeared in an array of red and yellow rectangles and the distractors were 2 or 5 small green squares. No correlation was found between the two tasks and each was correlated with different other measures that were focused on the same modality. For instance, visual distractibility was correlated with increased misses on the continuous performance test, and aural distractibility was correlated with IQ and reading scores on the WISC-R. While these tasks were different in many ways other than simply tapping auditory or visual processing ability, by dividing the participants into those who were not extremely distractible, those who were visually distractible, those who were aurally distractible, and those who were distractible by both visual and auditory stimuli, an interesting pattern emerges. No child could be described as distractible in both tasks, but six children were categorized as visually distractible, 10 children were aurally distractible and the remaining children were not distractible. However, the reaction time and accuracy scores of these children in the no distractor conditions were not significantly different from one another showing that these groups were not poorer performers in general, only in the presence on the distractors. This finding supports the claim that distractibility is not a single construct or controlled by the same mechanism but varies based on modality of the distraction.

The neuroimaging literature presents more evidence for the difference between how children and adults process stimuli presented in different modalities in the development of selective attention. Benedict et al. (1998) used PET to investigate the difference in how adults perform a focused and divided attention continuous performance test with and without auditory distractions. In summary, each participant was required to complete three different conditions: a simple auditory attention task in which the participant must identify a target syllable which was presented sequentially with other syllables, a focused auditory attention task in which the participant again was identifying the target syllable but in the presence of a distracting simultaneously presented text passage, and in the divided auditory attention task, participants were required to listen to the text passage as well as identifying the target syllable. They found increased activity of the anterior cingulate gyrus, the lateral frontal lobes, but not the superior parietal lobe. These areas corresponded with the areas identified by Fan, McCandliss, Flombaum, and Posner (2003) that measure the executive control and alerting aspects of attention. They also found activation of the left inferior parietal lobe, which was hypothesized to be involved in auditory attention.

Utilizing the developmental progressions of the three networks of the ANT as discussed by Rueda et al. (2004), some predictions were made. Their results for visual attention indicated that the alerting mechanism is still developing in middle childhood, the orienting mechanism has completed development for the most part by age 6, and the executive control mechanism continues development until age 7 when it is very comparable to adult levels. Since however, the executive control network was not being altered by the modification and the alerting network should remain stable since the auditory cues can still serve the purpose of warning (Guttentag, 1985), these two networks are not predicted to show any significant changes. Based on the findings of Robinson and Sloutsky (2004) and Sloutsky and Napolitano (2003), children might be able to process the auditory warning cues more easily and quicker than the visual cues due to a dominance of auditory stimuli processing over visual stimuli processing. The result of this would be better performance for younger children in the bimodal version than the original version in the orienting network scores. This improvement is also short lived because visual dominance begins to set in during middle childhood. This hypothesis supports the modality specific attentional mechanism because it should be clear that the two mechanisms were developing at very different rates and the auditory mechanism was superseded by the increasingly developed visual attentional mechanism in later childhood.

Detrimental Effect Hypothesis

In this hypothesis, only one mechanism of attention is proposed but that mechanism is extremely limited in its capability to process one modality of stimuli when a different distractor modality is present. For example, when driving an automobile and talking on the cell phone, the driver can be so distracted as to perform equally to a driver that is intoxicated (Rakauskas & Ward, 2005). While driving and talking are both considered somewhat automatic, the driving performance is severely impaired because of the demands of cross-modality stimulation, production, and comprehension. This hypothesis predicts that the auditory cues would create a distraction, regardless of their beneficial purpose, that would cause a decrease in performance in the visual aspects of the task, especially in the children (Hanauer & Brooks, 2003). The inspiration for this hypothesis came from the literature on auditory distractions. The more defined predictions for the developmental progression supporting this hypothesis will follow that discussion.

Two paradigms are commonly used to describe the negative effects of auditory stimuli on a visual task, which will be discussed in turn: the irrelevant sound effect and the cross-modal Stroop. Elliott (2002) explored how children and adults were negatively affected by the presence of tones and speech during a serial recall task. Participants were shown the a list of digits (number of digits per list determined by the highest list length in which one list was correct in a previous simple span test) to be recalled and there were three basic differences: some had tones played one per second during digit presentation, some had words played one per second during digit presentation, and some with silence during the presentation. She found that age played a significant role in how much disruption was caused by the sounds and words. The youngest group (second graders) showed the greatest disruption especially when the words or tones changed during presentation. The adults also show a similar, but less dramatic pattern of results indicating that they were affected by the tones and words, but not to the same degree that the children were affected. It was concluded that the difference in performance was due to the lack of attentional control and resources in children as compared with adults. This lack of resources and control would predict that children would perform less well on any task in which another stimulus was involved. It is also possible that children treat sounds and words differently than adults and therefore cannot inhibit the processing of such stimuli.

Another bimodal task that used sounds as a distraction was the cross-modal Stroop task (Cowan & Barron, 1987). This task required the participant to name the color of the square presented on the computer screen while ignoring the words played through the headphones. The words consisted of color words other than the color of the square presented on the computer screen, non-color words, and silent conditions. Elliott, Cowan, and Valle-Inclan (1998) used this task and manipulated the presentation time of the auditory distractors. The auditory stimulus was presented either 500 ms before the block appeared or simultaneously with the color block. Adults performed equivalently when a distracting color word was played 500 ms before the block appeared or when the non-color word was played 500 ms before the block appeared. When the auditory stimulus was presented simultaneously with the color square, adults took much longer to respond when the stimulus was a color word than when the stimulus was a non-color word, indicating that the color word produced more interference to performance of the task than the non-color word.

Hanauer and Brooks (2003) were the first to publish an article that tested the effects of the cross-modal Stroop task with children. Their participants ranged in ages from 4 to 11-years-old and were divided into three groups: 4-5 year-olds, 6-7 year-olds, and 9-11 year-olds, along with a group of adults. They found a significant cross-modal Stroop effect for all age groups, with the effect getting smaller with increased age. Elliott, McDonald, Lynn, and Alonzo (manuscript in preparation) utilized the cross-modal Stroop task with children and adults in three different experiments. Their findings were mixed in regard to the cross-modal Stroop effect. The main conclusion was that they could not find a replicable effect with children ages 5-11 years. Many manipulations were tested to replicate the findings of Hanauer and Brooks (2003) so one must reconsider whether other variables could be at work in this paradigm. For instance, perhaps children treated the sounds as warnings in the 500 ms-before-target-presentation condition instead of interference occurring due to the color word conditions in the manner similar to the adults in Elliott et al. (1998). It is also a possibility that due to less experience with colors, the children can utilize them as categorical primes such as for adults, the word “sock” can prime the naming of “shoe.”

The second hypothesis predicts that children’s ability to process auditory stimuli is so poor that the young children become unable to even perform the task correctly, which is relatively simple in the visual modality. The results of Elliott (2002) showed that sounds decreased the ability to accurately perform the primary task. If children are less able to process the tones, then performance will suffer dramatically. If the auditory stimuli are processed initially, then there may not be enough capacity, especially for the children, to process the visual element of the task, leading to very poor performance in all aspects of the task. But specifically, the most dramatic increase in RT should be seen in the orienting network scores. In the worst case, children may be so distracted by the auditory warning cues that they perform every aspect of the task worse than performance in the original version of the ANT. The deficit in performance should decrease as age increases.

Overall Slowing Hypothesis

This hypothesis proposes a single attentional mechanism similar to that proposed by Cowan (1999) and Engle, Kane, and Tuholski (1999), in which the mechanism is limited and domain general. The primary difference between this hypothesis and the Detrimental Effect Hypothesis is that there is no dominance for auditory stimuli processing or visual stimuli processing and the capacity is not preferentially distributed. In this study, support for this hypothesis would be seen in worse performance in the bimodal version than the original version and in linear increases for both versions in performance as age increases. The reason for worse performance in the bimodal version is that this hypothesis suggests that the auditory warning cue is "translated" into a visual expectation; whereas, in the original version, no translation step is required. This extra step leads to increased RT, and poorer accuracy when not processed correctly. The linear increase in performance is predicted because of the processing speed literature, which suggests that the mechanism controlling speed of mental processing increases from childhood to adulthood in a quantifiable amount.

Kail (1986) reported the results of three experiments, using primarily mental rotation tasks but also a name retrieval task with 12 groups of children ages 8-15 and young adults ages 18-21. In experiment one, participants saw pairs of alphanumeric symbols and their job was to identify whether the two symbols were identical or mirror representations regardless of how the stimuli were rotated. They also performed a task in which they saw objects in various forms and had to identify whether it was identical in physical form, in name, or in both aspects. They found that in the first experiment a linear and exponential growth curve fit the data better than a hyperbolic model and that the rate of change remained very similar for both tasks.

In experiment two, participants again did the mental rotation task with more trials and for this experiment, no feedback. Once again, the data provided support for an exponential growth function although the difference between this function and the hyperbolic model was small. The hyperbolic function could account for learning and practice curves with this task. In the third experiment, they limited the groups to 10 year-olds and undergraduates and they used a similar mental rotation task. The primary difference between the mental rotation task utilized before and the one for this experiment was that for this one, they used two stimuli letters and included a new variable (stimuli degradation). Participants viewed one letter at a time and were to report whether the letter was backward from normal presentation of that letter or not. The correlations between the children's response times and the adults' response times show that the processing involved is not based on increased knowledge with age but is a true aging effect. All of the findings in the three experiments support the global speed hypothesis. In reference to which general mechanism is affecting the speed of processing, he was able to rule out the usage of more complex strategies with age, in support of the quantity of processing resources increasing with age.

From this study and other similar studies (Kail, 1991; Salthouse & Kail, 1983; and Kail & Salthouse, 1994), Kail, in corroboration with Salthouse, has concluded that there is one mechanism that is responsible for the different speeds of performance across the life span. They also believe that this mechanism is very important to the study of cognitive processes because it affects everything from rehearsal speed to activation from long-term memory (Salthouse & Kail, 1983). This hypothesis, the global speed hypothesis, has even been quantified for the comparison of both children and older adults versus younger adults in the equation $\text{RT}_i = m\text{RT}_a$ where RT_i is the response time for participants of a particular age, RT_a is the response time for younger adult participants, and m is the slowing coefficient (Kail and Salthouse, 1994). This multiplicative model has led to many meta-analyses, in which correlations of response speed were very close to one, indicating support of their hypothesis of a general slowing mechanism and m (the slope of the equation and the slowing coefficient) was similar across experiments and ages, which also supports their hypothesis.

In relation to this hypothesis, all of the network scores for the bimodal version will be poorer than the original version and scores should improve with age. The performance for the bimodal ANT should be parallel to the original ANT in all of the networks. However, like the other hypotheses, the orienting network should be the most affected by the change in the modality of the warning cue in the adults and this should also show the greatest difference in the children. It was predicted that there would be a greater difference in performance at each level but a parallel trend because the children are simply slower processors. This hypothesis posits that the bimodal task will cause slowing in any individual because the translation process is basically a constant factor that causes the process to take more time. Development is also a constant factor because children are slower processors than adults. If support for this hypothesis is found in the proposed experiment, it will also be support for the unitary mechanism for attention because the developmental paths remain the same, just slowed somewhat because of the difficulty of processing the extra translation step. In other words, when a spatially-informative cue and target are presented in the same modality, the processing required for the expectation of the target is automatic and immediate, but when the cue was in one modality but is spatially-informative for the target in the other modality, that cue must be translated from the first modality into the expectation of what is about to occur in the target modality. This hypothesis is different from the Beneficial Effect Hypothesis because of the differences in the youngest two groups. The results for the oldest child group and the adult group will look the same for both hypotheses because any possible visual dominance has set in overriding the response preference to the auditory stimulus. The effect is then a general slowing effect for the older two groups.

General Predictions and Summary

Regardless of the hypothesis, several predictions were made for the series of experiments. It was predicted that adults would be able to utilize the warning tones in a similar manner to the visual warning cues because of their mature attentional system(s). This use of the cues will be seen by the comparison of the network scores for the orienting network. It is also predicted that all of the network scores will correlate with the corresponding network scores from the other version of the task. For instance, the executive control score from the bimodal ANT would correlate with the executive control score from the original ANT. It is also predicted that the results for the original versions will replicate the findings of Fan et al. (2002) and Rueda et al. (2004) depending on the version utilized and the ages being tested.

There are several benefits of the design of this study. Not only is the modified task used to measure performance of the bimodal attention mechanisms but it will be utilized in direct comparison with the original ANT because they have very similar components. Since the three mechanisms of attention can be isolated through difference scores with this task, the impact of auditory warning cues on attention can be more precisely measured. Another interesting element to the proposed research is the possibility of correlations between the three measures of attention. If these correlations occur in the bimodal version, it could be evidence of the mechanism that processes the auditory cues into a visual expectation or even evidence of the episodic buffer proposed by Baddeley (2000) in his most recent revision of the working memory model. The episodic buffer is proposed as a mechanism that is able to store and manipulate information simultaneously whereas, the slave mechanisms (phonological loop and visuospatial sketchpad) are only capable of storage. If a correlation exists between executive control, per see, and orienting in the bimodal version only, this could indicate that the episodic buffer is at work.

Another very important aspect of this study is its ability to measure the development of bimodal attention by using the task with school-aged children. Through the experiments already cited, we know that children are affected to a greater degree by distracting sounds (Elliott, 2002), that children often prefer auditory stimulus (Sloutsky & Napolitano, 2003) but overall children seek to process the simplest stimulus (Robinson & Sloutsky, 2004). By using young children ages 5-6, this study can compare the ability to process the warning tones as compared to the visual warning cues. By using older children ages 9-10, this study can compare the original ANT to the bimodal ANT to see if the path of development is mostly complete for bimodal attention as it is for visual attention (Rueda et al., 2004). By including an intermediate group of children ages 8-9, this study can compare the development of the ability to utilize sounds with the inability to ignore sounds (Elliott, 2002).

Another way that this research can increase knowledge of auditory attention is to illuminate the age at which sounds can be used as a facilitator instead of a distractor during a task. If the ability to process stimuli is limited or consolidated at young ages, then the warning tones may be a distractor from the task of indicating the direction of the target, but if the ability to process stimuli is divided by modality or if children have an innate preference for processing auditory stimuli, then children may be more able to quickly and proficiently utilize the warning tones than the visual warning cues. Experiments 1A and 1B were conducted to test the implementation of the bimodal task on a college-aged population using the adult version of the ANT. Experiment 2 was conducted to compare children and college students on the child version of the ANT.

EXPERIMENT 1A

The goal of this experiment was to test the viability of utilizing the bimodal ANT. Additionally, a direct comparison was made with the original ANT in a within-subjects design. Adult data was collected for comparison to the child participant data.

Method

Participants

Sixty-five participants from Louisiana State University volunteered to receive optional course credit. These participants included 46 females and 19 males and the average age of the participants was 19.51 years (*SD* = 1.16) with ages ranging from 18 to 24. All participants indicated having normal or corrected-to-normal vision and normal hearing. Twelve participants were not included in the above sample due to several circumstances: one participant not included in the above sample reported hearing loss, three reported taking prescriptions for ADHD, seven participants were below 3 standard deviations for accuracy on one or both of the ANT tasks, and one was not able to reach 90% accuracy on the Tone Practice.

Design

Both ANT programs had similar designs. The original program is a 3 x 4 within-subjects factorial design with three levels of the flanker type (neutral, congruent, or incongruent) and four levels of the warning cue type (center, double, spatial, and no cue conditions). The conditions where the asterisk was presented above or below the fixation cross were combined to create the spatial cue condition. The flanker variable was identical in the bimodal ANT; however, the warning type was changed. In the bimodal ANT, the warning variable is very similar but was relabeled to describe more accurately the nature of the tones that were utilized. To be precise, the center cue in the original ANT corresponded with a middle tone in the bimodal ANT, the double cue in the original ANT diffused attention in hypothetically a similar manner to the chord utilized in the bimodal ANT, the spatial cue corresponded to the spatial tones (high and low) in the bimodal ANT, and the no cue condition is the identical to the no tone conditions.

Another program was incorporated to ensure that participants could differentiate between the warning tones being used in the bimodal ANT. This program, called tone practice, briefly plays the four tones (high, low, middle, and chord) and then requires the participants to indicate which tone they hear during each of 20 trials. Each tone is played in random order five times and participants used the number pad to respond. For example, after all tones were identified and played at the beginning of the task, an individual tone was played and the participant was required to press “1” for a high tone, “2” for a medium tone, “3” for a low tone, and “4” for the chord. The instructions regarding which key corresponded with which tone was shown during the entirety of the task. At the end of the program, the percentage correct is displayed. Participants were required to get 90% or more correct and if they failed to meet that criterion, they were allowed to try the program again up to four additional times.

Overall, performance on the tone practice program was very good. Twenty-seven participants met the 90% criteria in the first attempt at the program. Another 26 participants met the criteria after the second attempt. These two groups made up 81.5% of the total sample. Seven participants required three attempts, four participants required 4 attempts, and one participant was able to meet the criteria after 5 attempts. After averaging all of the attempts for all of the participants, the average for the group was 88% (*SD* = .09). Only one participant did not succeed after 5 attempts at the tone practice program and that data was excluded from the sample.

Partial counterbalancing of the order of the three programs was used to eliminate order effects. Participants either performed the original ANT program first, then the tone practice program and lastly the bimodal ANT program, or they performed the tone practice program first, followed by the bimodal ANT program, and finally they completed the original ANT program.

Materials

All programs were created and presented using a scripting language software package named E-Prime (Schneider, Eschman, & Zuccolotto, 2002), and participants used IBM compatible personal computers to complete the programs. The two mouse buttons were implemented as the response keys. Only during the tone practice program and the bimodal ANT program were the participants required to wear headphones. The visual stimuli used for the ANT programs were identical and consisted of five horizontal black lines with or without arrows on each called the target set. The arrows always point to the left or the right of the screen. The central line always had an arrow connected to it and this central line is the target stimulus. The arrows appeared above or below a small fixation cross in the center of a white screen. Three configurations of the arrows and lines create the flanker variable, and these are as follows: a configuration with 5 lines and only one arrow on the central line (neutral flankers), five lines with five arrows that point the same direction (congruent flankers), and five lines with the central arrow pointing the opposite direction of the other four arrows (incongruent flankers).

During the original ANT program, asterisks sometimes appeared shortly before the target set appeared on the screen. These asterisks are cues which indicate that the target will soon appear, and in some cases, where the target set will soon appear. Four different placements of the cues are utilized which are as follows: one asterisk in the same place as the fixation cross, one asterisk above the fixation cross (where the target set will appear shortly), one asterisk below the fixation cross (where the target set will appear shortly), or two asterisks which appear simultaneously in both the upper and lower positions. These conditions are called center, high, low, and double cues, respectively. There is also a no warning cue condition in which no asterisk appeared between the beginning of fixation and the onset of the target set.

During the bimodal ANT program, all asterisks were removed and tones were substituted in their places. The tones performed the similar task of indicating the target set would soon appear and in some cases where the target set would appear. The tones utilized for this experiment consist of a low tone (122 Hz), a high tone (1960 Hz), a middle tone (490 Hz), a chord of simultaneous notes, and silence. The high and low tones were used to indicate position similarly to the high or low asterisk. The middle tone mimicked the center asterisk, which appeared in the place of the fixation cross. The chord substituted for the two asterisks warning and silence replaced the no cue condition.

The original ANT program was identical to the one used by Fan et al. (2002) except the instructions regarding the purpose of the asterisks were removed from the instruction screen. The bimodal ANT program was based on the original program with identical instructions without the asterisks section. The decision to remove the instructions regarding warning cues was made to test if the tonal cues would be as robust as visual cues.

Results

The means of the medians were used to avoid the problem of skew when using response time data, and to replicate the method of Fan et al. (2002). The mean response times will be discussed first and will be followed by a discussion of the accuracy for the original ANT and the bimodal ANT. The mean response times are shown in Figure 1 for the original and Figure 2 for the bimodal version. The error rate percentages can be found in Figure 3 for the original version and Figure 4 for the bimodal version.

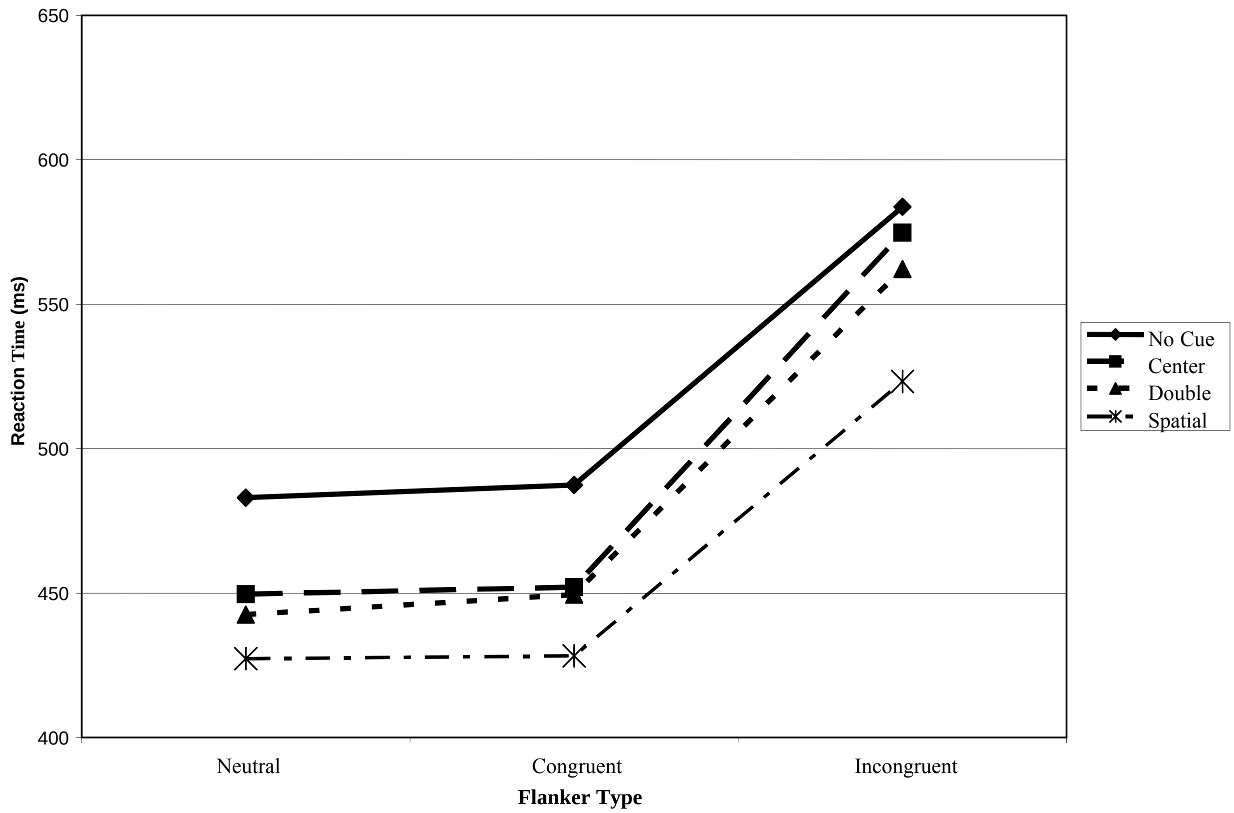

Figure 1. Mean of the median response times for Original ANT in Experiment 1A

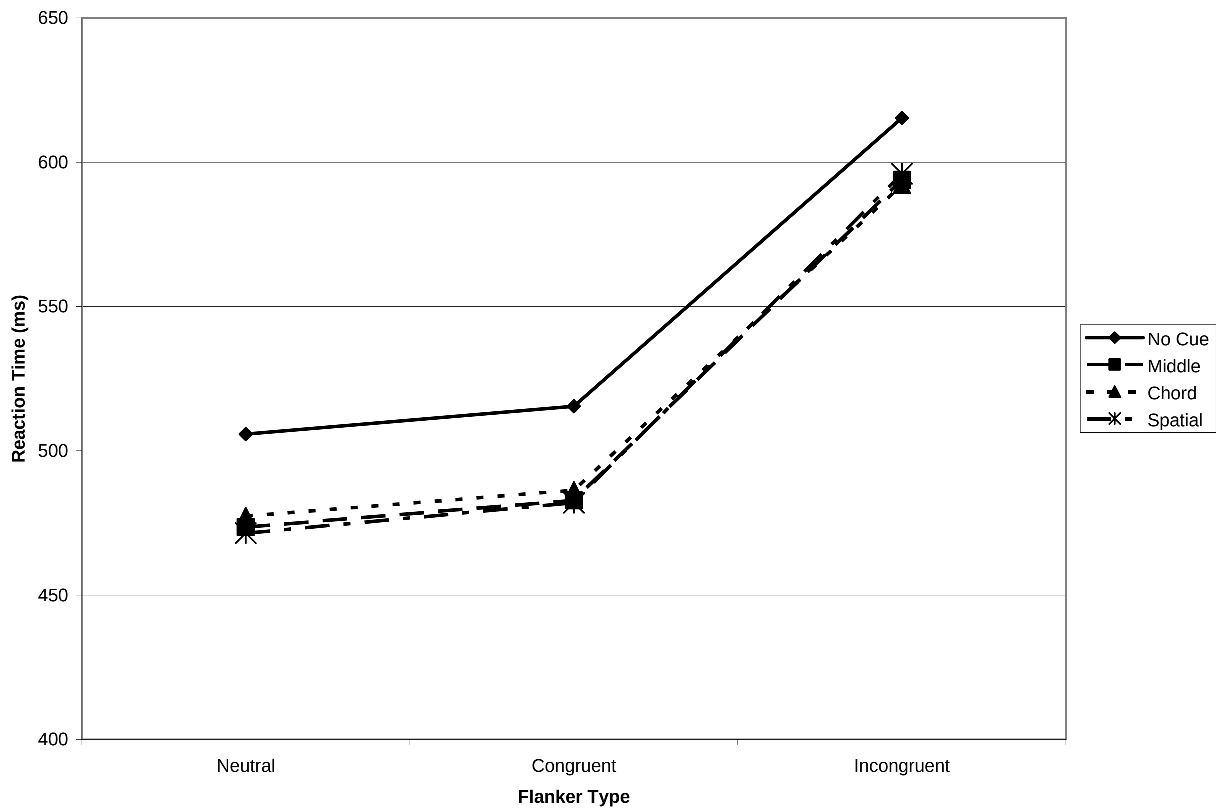

Figure 2. Mean of the median response times for Bimodal ANT in Experiment 1A

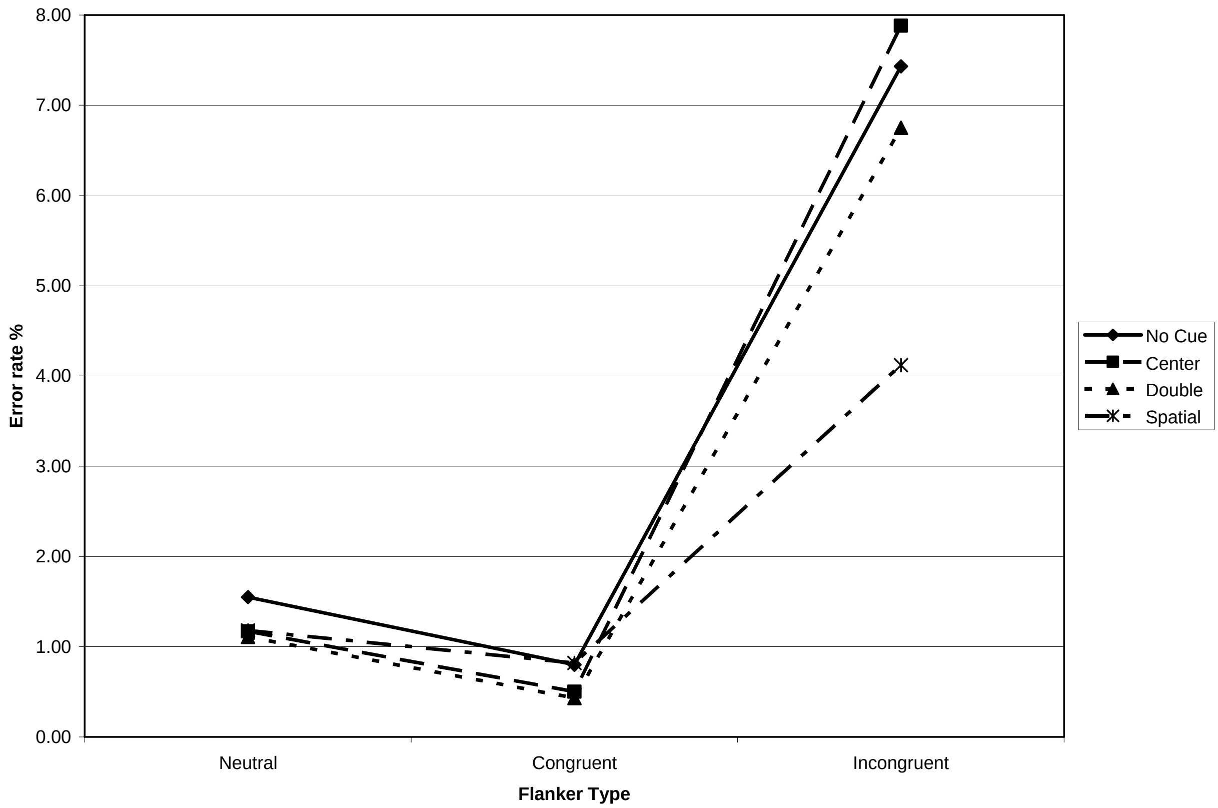

Figure 3. Percentage of error rates for Original ANT in Experiment 1A

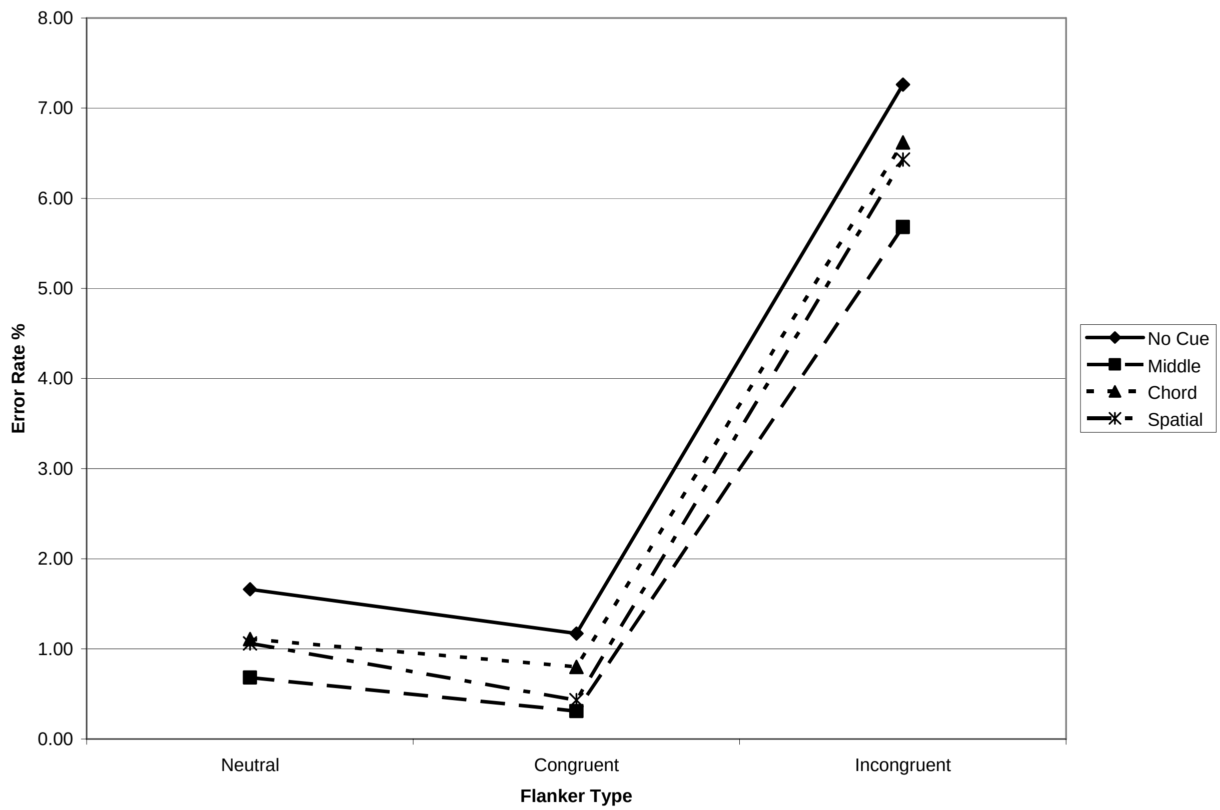

Figure 4. Percentage of error rates for Bimodal ANT in Experiment 1A

No significant order effects were found, thus this variable was not included in any additional analyses. A 2 (version: original or bimodal) x 3 (flanker type: neutral, congruent, and incongruent) x 4 (warning type: center or middle tone, double or chord, spatial, and no cue) within-subjects ANOVA was performed on the mean of the medians RT data (see Table 1). All ANOVAs were followed by pair-wise comparisons with Bonferroni corrections. All significant differences reported from these analyses were significant at the $p < 0.05$ level.

Table 1. Analysis of Variance for Response Time Performance for Experiment 1A

Source	*df*	*F*	η_p^2	*p*
	Within-subjects			
Version (V)	1	103.91**	0.62	0.01
Flanker (F)	2	740.05**	0.92	0.01

(Table 1 cont.)

Warning (W)	3	152.14**	0.70	0.01
V error	64	(4781.15)		
F error	128	(2867.75)		
W error	192	(861.62)		
V x F	2	3.55*	0.05	0.03
V x W	3	29.60**	0.32	0.01
F x W	6	5.73**	0.08	0.01
F x W error	384	(466.10)		
V x F x W	18	5.29**	0.08	0.01

Note: Numbers in parentheses represent the mean square error.
* This indicates significance at $p < 0.05$ level.
** This indicates significance at $p < 0.01$ level.

As seen in Table 1, the main effect of version was significant, as well as the main effect of flanker type and warning type. The main effect of version indicated that performance on the bimodal ANT was slower than the original ANT. The main effects of flanker and warning were complex so further analyses were completed on these variables to tease apart the significant differences. These analyses are discussed later in this section. All of the interactions were significant, including the 3-way interaction of version, flanker type, and warning type. The differences between the two versions were easily captured by visual inspection of the two graphs. In the original ANT, the pattern of differences for the flanker and warning variables are similar but vary in speed for each condition consistently with only the center and double cue conditions not differing significantly. In the bimodal ANT, there is a similar pattern but the spatial condition is not differentiated from the middle and chord conditions. In both versions, the neutral, congruent, and incongruent flankers have a similar pattern but once again, in the bimodal version, the RTs were slower but by different relative proportions.

Following up on the 3-way interaction, two 3 (flanker type) x 4 (warning type) within-subjects ANOVAs for reaction times were performed for each of the versions of the task to assess each version separately. For the original version, a significant main effect of flanker type was found, F (2, 128) = 608.05, $\eta_p^2 = 0.90$, $p < .001$, and for warning type, F (3, 192) = 162.36, $\eta_p^2 = 0.72$, $p < .001$. The main effect for the flanker condition was indicative of the fact that the incongruent condition was significantly slower than the congruent and neutral conditions, which were not significantly different from each other. The main effect for warning condition was driven by the no cue condition being significantly slower than the other conditions. The center and double cue conditions were significantly different (although they were practically very similar) with the double cue (*M* = 486.20, *SD* = 50.37) leading to faster response times than the center cue (*M* = 493.47, *SD* = 50.66). The spatial cue condition was significantly faster than the other three conditions. To put it simply, the no cue was slower than the center cue, which was slower than the double conditions, which was also slower than the spatial conditions. There was a significant interaction between flanker type and warning type, F (6, 384) = 11.80, $\eta_p^2=0.15$, $p < .001$. The interaction showed that in the original ANT the RTs were slower for the center and double cue conditions in the incongruent condition in comparison to the RTs for those conditions in the neutral and congruent conditions. These results replicate those of Fan et al. (2002).

For the 3 x 4 ANOVA of the bimodal version of the ANT, there was a main effect for flanker type, F (2, 128) = 646.85, $\eta_p^2 = 0.85$, $p < .001$, and a main effect for warning type, F (3, 192) = 44.75, $\eta_p^2 = 0.42$, $p < .001$. For the flanker variable all of the conditions were significantly different with the neutral condition being the fastest, followed by the congruent condition, and followed by the slowest incongruent condition. For the warning variable, the three conditions of double, spatial, and middle were the not significantly different but they were all significantly faster than the no cue condition. However, there was not a significant interaction for the bimodal version between flanker type and warning type. The lack of interaction showed that the warning conditions were the same distance apart for each level of the flanker variable. The primary difference between the bimodal version and the original version was that the bimodal version was slower. But another important difference was that performance in spatial cue conditions was not differentiated from the performance in middle and chord conditions in the bimodal version compared to the original version in which the spatial cue was much faster than all other conditions.

A 2 x 3 x 4 within-subjects ANOVA was also performed to analyze the accuracy scores for the two versions of the ANT. Overall, the accuracy data mirrors the RT data for both versions of the ANT. There were main effects for flanker type, F (2, 128) = 86.04, $\eta_p^2 = 0.57$, $p < .001$, and for warning type, F (3, 192) = 4.74, $\eta_p^2 = 0.07$, $p < .01$. There was a significant interaction between version and warning type, F (3, 192) = 3.47, $\eta_p^2 = 0.05$, $p < .05$, a significant interaction between flanker type and warning type, F (6, 384) = 2.47, $\eta_p^2 = 0.04$, $p < .05$, and a significant 3-way interaction between version, flanker type, and warning type, F (6, 384) = 3.25, $\eta_p^2 = 0.05$, $p < .02$. This interaction can be seen in Figures 3 and 4, which depict the error rate data. The 3-way interaction modified the interpretations of the main effects. It is apparent that in the original ANT, the error rates are very similar for all warning conditions in both the neutral and the congruent conditions but the error rates for the incongruent condition are more dispersed than the other two conditions and the incongruent condition for the bimodal ANT. One important aspect of Figure 3 is the location of the spatial incongruent condition in relation to the other incongruent conditions.

This difference shows how beneficial the spatial cues are to accurate performance as well as a quicker performance, which was analyzed in the RT data. In the bimodal ANT, the patterns of error rates are similar but more spread out than the original ANT for the neutral and congruent conditions.

This ANOVA was followed by two 3 x 4 ANOVAs to assess each version separately. For the original ANT version, there was a significant main effect for flanker type, F (2, 128) = 77.54, $\eta_p^2 = 0.55$, $p < .001$, and for warning type, F (3, 192) = 4.81, $\eta_p^2 = 0.07$, $p < .01$. In the flanker variable the incongruent condition had the most errors, the neutral condition had an intermediate amount of errors and the congruent condition had the lowest rate of errors. The warning variable results indicate that the double cue error rate was not significantly different than the other error rates but the spatial cue error rate was significantly higher than the center cue condition and the no cue conditions, which did not differ between each other based on error rate. There was also a significant interaction between flanker type and warning type for the original version, F (6, 384) = 5.41, $\eta_p^2 = 0.08$, $p < .01$. Once again the main effects were qualified by the interaction, which showed that the warning conditions were separated by different amounts of errors depending on the flanker condition. For the bimodal version, there was a significant main effect of flanker, F (2, 128) = 62.85, $\eta_p^2 = 0.50$, $p < .001$, and for warning type, F (3, 192) = 3.43, $\eta_p^2 = 0.05$, $p < .02$. The main effect for the flanker variable was due to the fact that there were significantly fewer errors made in the congruent condition and in the neutral condition but the incongruent condition had many more errors. In the warning variable, the error rates were not significantly different for the chord and spatial conditions but the middle condition had significantly more errors than the no cue condition. However, there was no significant interaction similar to the result of the RT ANOVA for the bimodal version because the paths were once again very parallel.

To find the network scores for the two versions of the ANT, the difference equations from Fan et al. (2002) were utilized. To find the alerting score, the mean RTs for the double cue or chord trials were subtracted from the no cue conditions. To find the orienting score, the mean RTs for the center or middle cues were subtracted from the spatial cue conditions. To calculate the executive control score, the mean RTs for the incongruent trials was subtracted from the congruent trials. All of the scores can be seen in Table 2.

Table 2. Network Scores (with *SD* in parentheses) for Experiment 1A and 1B

	Experiment 1A		Experiment 1B
	Original ANT	Bimodal ANT	Bimodal ANT w/ Ins.
Executive Control	104.31 (33.81)	108.95 (33.29)	117.72 (49.27)
Orienting	32.58 (25.72)	0.27 (16.44)	24.39 (27.31)
Alerting	33.35 (17.89)	29.05 (31.55)	28.54 (26.90)

The ideal results for each of the networks vary. The best outcome of the executive control network scores would be a small number because that indicated that the participant was able to resolve and respond to the conflicting stimuli as quickly as they were able to respond to non-conflicting stimuli. The best outcome of the orienting and alerting networks scores are larger numbers because this indicates that participants are able to utilize the warning cues for the alerting, and specifically spatial warning cues for the orienting, with great efficiency. To test the independence of the networks as well as to test the similarity between the two versions, a correlation analysis was completed (see Table 3). No correlations were found between the networks in the original ANT, which replicates the findings of Fan et al. (2002). The executive control network scores were significantly correlated between the two versions and this correlation was expected because no change was made to the aspects of the task that were measured by the executive control network. The analyses also showed a correlation between the orienting network in the original ANT and the orienting network in the bimodal ANT. This correlation was predicted in the hypotheses, but after analyzing the orienting network score, which showed that the spatial warning tones were not utilized properly, the correlation was not expected. One possible explanation for this correlation is that those participants who were able to utilize the auditory spatial warning tones were also best able to utilize the visual spatial warning cues. There was also a correlation between orienting network score in the bimodal ANT and the alerting score in the bimodal ANT. From the pattern seen in Figure 2, it is apparent that this correlation is due to the fact that the spatial cues were not utilized appropriately and thus were simply generic alerting cues. A correlation was found between the alerting network in the bimodal ANT and the executive control network in the bimodal ANT. This could have been due to the fact that the participants able to resolve the conflict in the incongruent condition quickly were not utilizing the auditory warning cues as much as others.

Table 3. Pearson's *r* Correlations of Network Scores for Experiment 1A

	1	2	3	4	5
Original ANT					
1. Executive Control	--	--	--	--	--
2. Orienting	-0.08	--	--	--	--
3. Alerting	-0.06	-0.19	--	--	--
Bimodal ANT					
4. Executive Control	0.70**	0.08	0.17	--	--
5. Orienting	0.01	0.25*	0.02	0.15	--
6. Alerting	0.19	0.06	0.09	0.32*	0.46**

Note:
** This denotes significance as $p < .01$
* This denotes significance as $p < .05$

Discussion

The results of the original ANT replicate Fan et al. (2002) quite closely. This is also support for the hypothesis that the visual warning cues are utilized automatically in this single modality task because participants were not given any instructions related to the purpose or even presence of the warning asterisks. However, it became very clear that the warning cues in the bimodal ANT were not utilized to their full capacity. In Figure 2, it was expected to see three clear paths: one for the slowest no cue condition, two together for the middle and chord conditions, and the fastest path for the spatial cue condition. There are only two paths in Figure 2, which indicate that participants were warned by the auditory cues but they did not utilize the spatial cues to decrease RT. The non-utilization of the spatial warning cues is also seen the orienting network score for the bimodal ANT. The score is very close to zero indicating that participants were equally fast whether there was a middle tone or a high or low tone before the target appeared.

The main effect of the different versions of the task seems to be driven by the fact that the bimodal version is slower overall than the original ANT. This is evidence for the existence of an extra processing step required for the auditory cue to be turned into a visual expectation, which supports the Overall Slowing Hypothesis and a single attentional mechanism. However, it could also be evidence for a slower auditory processing mechanism as compared to the visual processing mechanism, which is evidence for the two modality specific mechanisms model. While we were not able to differentiate between these two possibilities with this data set, further experiments will hopefully shed more light on these hypotheses.

The correlations between the network scores can be described as follows. The significant correlation between the executive control score for the original ANT and the bimodal ANT was expected because no modification was made to the flanker aspect of the task. The significant correlation between the orienting network in the original ANT and bimodal ANT was unexpected due to the outcome of the other analyses. This could be explained by the participants who were most able to use the spatial tones were also the most efficient with the spatial visual cues. There was a significant correlation between orienting in the bimodal ANT and alerting in the bimodal ANT. This is most likely due to the fact that in the bimodal ANT, participants were using spatial cues as simple warning cues instead of being able to predict the target location, so the networks measured the same thing. The correlation between executive control in the bimodal ANT and alerting in the bimodal ANT added support to the extra processing step hypothesis. While Fan et al. (2002) did not find any correlations between the networks, they did report that others have found correlations (Fossella et al., 2002) and that it could be expected. Although the networks do have distinct and separate biological correlates, these systems might be behaviorally reliant on one another. This finding could be a result of this behavioral reliance or it could also be a result of the manipulation of the ANT itself. In other words, the manipulation of the modality of the warning cue presentation could be adding extra processing steps, and therefore, involving the executive control network in the alerting network's processing.

Since it was not clear whether participants did not understand the purpose of the spatial tones in the bimodal ANT or if they simply lacked the processing ability to utilize them efficiently, it became obvious that a second experiment was necessary to differentiate these hypotheses. It was especially vital because if the adults were not capable of utilizing the spatial tones, it would be less likely that children would be able to use these cues. This inference was the motivation for the next experiment, because the ability or inability to use bimodal selective attention as an adult would be important for the predictions of performance in this task over the course of child development.

EXPERIMENT 1B

In Experiment 1A, the instructions regarding the warning cues were excluded from the procedure. However, the participants did not seem to understand the purpose of the auditory cues. This experiment was performed to discover whether participants could use the auditory cues if specifically told their purpose.

Method

Participants

Eighty-four undergraduates at Louisiana State University participated to earn optional course credit for psychology courses. These participants included 15 males and 69 females, ages 18-29 years (*M* = 19.73, *SD* = 2.12). All participants reported having normal or corrected-to-normal vision and normal hearing. Sixteen participants not included in the above sample were excluded due to technical difficulties, 6 participants were not included due to failure to meet the criteria set for the tone practice program, and 1 participant was not included due to self report of taking ADHD medication.

Design

The design was identical to the design of Experiment 1A except that no counterbalancing was required since only the bimodal ANT was used. Participants were required to meet the criteria for the tone practice program and then go on to complete the bimodal ANT program. The criteria remained the same: 90% correct with 5 chances to perform the program. Participants performed very well during the tone practice program. Fifty-two participants only required one attempt to meet the criteria. Twenty-four participants required 2 attempts and the remaining eight participants required 3 attempts. The average accuracy for all attempts for all participants was 91% (*SD* = .07). After the participants finished the tone practice program and met the criteria, they were read a script of the instructions for the bimodal ANT program by the experimenter. This script can be seen in Appendix. Basically, it explains how to respond to the stimuli, the purpose of the warning tones, and an encouragement to utilize the warning tones.

Materials

The materials and programs used in this experiment were identical to those used in Experiment 1A with the exclusion of the original ANT program.

Results

The mean RT and error rate scores can be found in Figures 5 and 6, respectively. A 3 x 4 within-subjects ANOVA was performed on the RT data and then a similar analysis was performed on the accuracy data. The results of the RT data were a significant main effect of flanker type, $F\ (2, 166) = 517.93$, $\eta_p^2 = 0.86$, $p < .001$, and a significant main effect for warning type, $F\ (3, 249) = 104.47$, $\eta_p^2 = 0.56$, $p < .001$. All of the flanker conditions were significantly different from each other with the neutral condition being the fastest, then the congruent condition, and the incongruent condition was the slowest. The main effect for the warning variable showed that the no cue condition was the slowest, the middle and chord conditions were not significantly different, and the spatial condition was the fastest. There was also a significant interaction between flanker type and warning type, $F\ (6, 498) = 2.48$, $\eta_p^2 = 0.03$, $p < .05$. This interaction indicates that, similar to but slower than the original ANT results, the difference in speed between the middle or chord conditions and the no cue condition decreased from the most difference in the neutral condition, to slightly less in the congruent condition, and an even smaller difference in the incongruent condition. In contrast, the difference between RTs for the spatial and no cue conditions stays similar across the flanker variable.

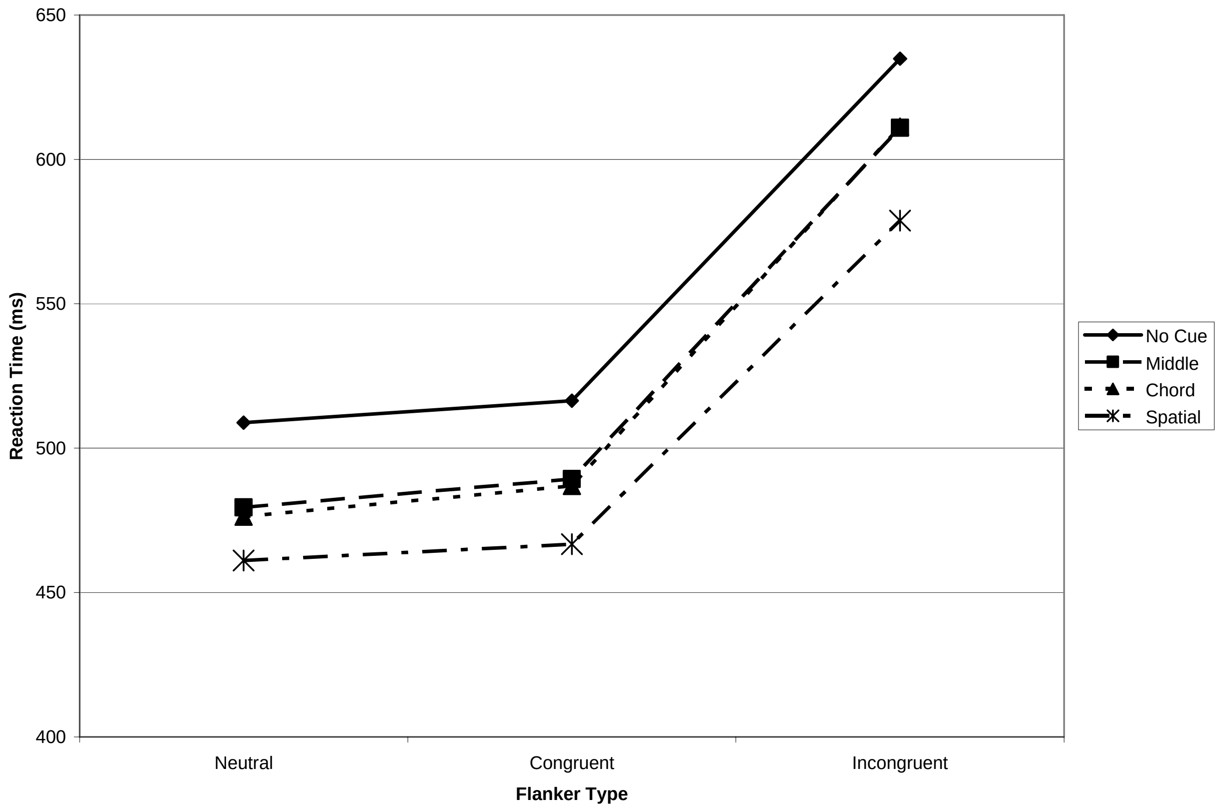

Figure 5. Mean of the median response times for Bimodal ANT in Experiment 1B

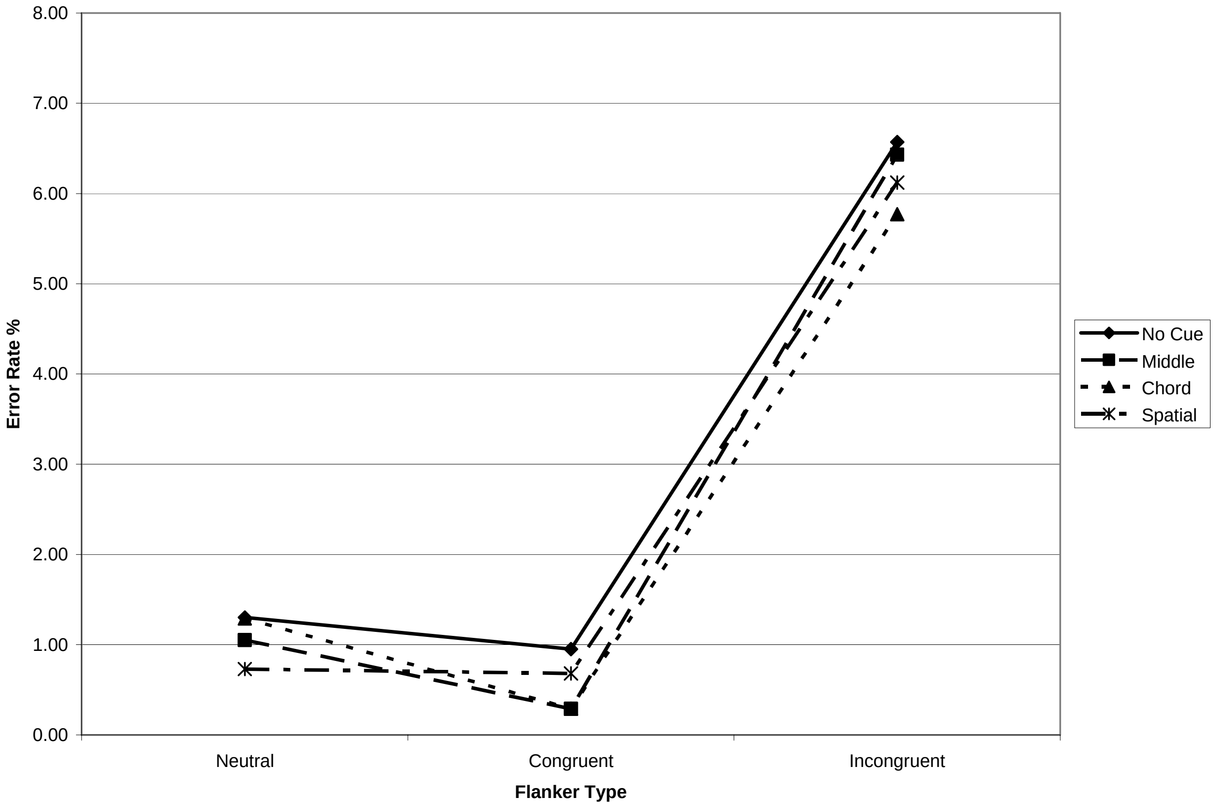

Figure 6. Percentage of error rate for Bimodal ANT in Experiment 1B

The results of the accuracy data were very different. The only significant main effect was for flanker type, F (2, 166) = 96.38, $\eta_p^2 = 0.54$, $p < .001$. The number of errors was the least in the congruent condition, intermediate in the neutral condition, and by far the greatest in the incongruent condition. The main effect of warning type and the interaction between flanker and warning type were not significant. The warning conditions were all very close together which resulted in no main effect and no interaction. The warning conditions are not parallel in terms of the flanker variable, whereas in the first bimodal version they are parallel but all of the error rates are so close together for the warning variable in each of the flanker conditions that there is not a significant difference in the warning conditions or between the congruent and neutral conditions. The results for error rates for the second bimodal ANT with instructions looked more similar to the first bimodal ANT but were closer together, which eliminated the main effects and significant differences.

The network scores for this experiment can be found in Table 2 and were calculated in an identical manner to those in Experiment 1A. The key distinction of the new network scores was the closeness between the orienting score in the bimodal ANT with instructions and the original ANT. The only significant correlation within the bimodal ANT with instructions is the one between the orienting network and the executive control, $r = -0.37$, $p < .01$. This correlation could indicate that participants able to utilize the spatial tones were also more able to inhibit the conflict of the incongruent trials and respond more comparably to performance in the congruent trials. The correlations between alerting and executive control and the alerting and orienting networks were not significant ($r = 0.17, -0.01$, p's $> .05$, respectively). It was predicted that the scores would remain statistically equal between the bimodal version and the original version so a Tukey post-hoc test was conducted on all of the network scores from both experiments to explore that prediction. It found that the executive control and the alerting scores did not differ across the experiments and versions. However, the orienting network scores differed significantly. The test found that the bimodal ANT in Experiment 1B was statistically equal to the original ANT in experiment 1A but both were significantly different from the bimodal ANT in experiment 1A.

An additional set of analyses was completed with the goal of determining whether practice effects within each version could give any support for the claim that auditory warning cues cause an extra processing step in the performance of the bimodal task. Only the data from the original ANT and the bimodal ANT with instructions were analyzed by looking at the reaction time in each of the three blocks (not including the practice block). The first version of the bimodal ANT was excluded because the original ANT provides a baseline and the bimodal ANT with instructions was the only bimodal version in which participants showed evidence of utilizing the spatial cues correctly. The analyses performed include the 3 (block) x 3 (flanker) x 4 (warning) within-subjects ANOVAs for each of the tasks.

For the 3 x 3 x 4 ANOVAs, only the original version had a significant main effect for block (F (2, 128) = 5.03, $\eta_p^2 = 0.07$, $p < .01$) and that version also had a significant interaction of block x flanker (F (4, 256) = 2.97, $\eta_p^2 = 0.04$, $p < .05$). The main effect indicated that the third block was significantly faster than the first two blocks. The interaction was explored by 3 one-way ANOVAs for the flanker types but there were not any significant differences between the blocks for any of the flanker conditions. The bimodal version had a significant interaction of block x warning (F (6, 498) = 3.15, $\eta_p^2 = 0.04$, $p < .01$) and three one-way ANOVAs for each warning condition were performed to explore that interaction. There were no significant differences found between the blocks for any of the warning conditions.

Discussion

The major finding of this experiment was that adult participants were capable of utilizing spatial auditory warning cues efficiently. Overall, the patterns of results for the second attempt of the bimodal ANT were very similar to those of the original ANT. The key difference was that RTs were still slower than in the original task. While this result did not differentiate between the two hypotheses proposed in the first discussion, it did indicate the stability of the finding even after a change in performance.

Another important aspect of this experiment is the lack of a correlation between the executive control score in the first two versions of the ANT and the bimodal ANT with instructions. It was previously hypothesized that since the aspects of executive control network were not altered, all three versions should correlate on this measure. Since the executive control networks correlated in the first two versions, the original ANT and the bimodal ANT, it is probable that there is an elementary difference in the processes required for the original ANT and the bimodal ANT with instructions. This finding was not conclusive evidence for either of the hypotheses regarding the unitary or modality specific nature of attention but different interpretations could be made in reference to the two hypotheses. In support of the unitary hypothesis, one could argue that the processing requirements to translate an auditory cue into a visual expectation are so great as to deduct from the necessary requirements to perform the flanker aspect of the task efficiently. However, when the modality specific attention mechanism for auditory stimuli is engaged, the task could fundamentally change in the visual attention mechanism as well, which would lend support to the modality specific mechanism of attention. The original motivation for analyzing potential practice effects related to the hypothesis of an extra processing step required by the transition from the auditory to the visual modality. Support for this was not found in the analyses completed, but was investigated again by analyses of the practice effects in the next study.

EXPERIMENT 2

This experiment built upon the first experiments, and once again, involved a modification of the original ANT task by Fan et al. (2002) in which the visual warning cues were removed and replaced with warning tones. By making this modification, the task became a bimodal version that allowed for measurement of participants' ability to utilize auditory cues during a visual flanker task. The primary difference in this experiment was the inclusion of three child groups. The inclusion of the groups was necessary for the examination of the developmental changes involved in bimodal attention as compared to visual attention measured by the ANT. Comparison of the attentional networks allowed for tests of the hypotheses because specific predictions were made for how each network would develop differently for both versions.

Method

Participants

The final sample in this study was 19 kindergarteners (*M* = 73 months, *SD* = 4.69, 11 females), 20 second graders (*M* = 95.75 months, *SD* = 3.93, 12 females), 23 fourth graders (*M* = 118.3 months, *SD* = 3.46, 12 females), and 31 adults (*M* = 20.09 years, *SD* = 1.74, 24 females). These participants were recruited from the LSU Laboratory School and the undergraduate research pool at LSU. Four children (2 kindergarteners and 2 fourth graders) not included in the above sample were excluded due to extreme external distractions during the session, and 2 children (1 kindergartener and 1 second grader) were not included due to their decision not to complete the tasks. After closer inspection of the data, 2 children (1 kindergartener and 1 second grader) were not included due to the fact that more than 50% of the data points for certain conditions were missing from the RT analysis because of inaccuracy. Three adults that participated were not included in the sample due to accidental deletion of instructions and 1 adult was not included because of the reported use of ADHD medication. Child participants were rewarded with $10 for their participation along with stickers during the sessions to allow for short breaks and to keep a high morale. Adult participants received extra credit in a psychology course as a reward or as fulfillment of a partial course requirement in an introductory psychology course.

Design

The design was similar to Experiment 1A; it was a within-subjects design with the children completing each version of the ANT and the tone practice program. Due to concerns that the children would become overly fatigued or bored completing 40 minutes of the same task, the experiment was split into 2 sessions. During one session, the child completed the original child ANT and during the other session, he completed the tone practice program and the bimodal child ANT. The tone practice program was completed twice by the participants who did not perform very well the first time. These sessions were separated by about 3 weeks (M = 20.55 days, SD = 1.19, Range 16-24 days). The sessions were counterbalanced to control for order, testing, or history effects. The adults completed all three programs in one session but that session was partially counterbalanced in an identical manner to Experiment 1A.

Materials

The materials for this experiment were similar to those utilized in experiment 1A except that simplified version designed for children by Rueda et al. (2004) was substituted for the version of the ANT created by Fan et al. (2002). The child version of the ANT (Rueda et al., 2004) was modified to include the same tones as in the adult bimodal version. The child version contained very similar characteristics to the adult version, with a few small differences. The largest difference was the substitution of line drawings of fish instead of arrows. These fish were yellow on a turquoise blue background. The warning cue was presented for 150 ms instead of 100 ms and the fixation cross between the warning cue and target presentation was increased from 400 ms to 450 ms. The number of trials was decreased from 96 trials in three blocks to 48 trials in three blocks. In the child version, the neutral condition presents one fish alone, whereas in the adult version, the neutral condition has five lines and one arrow attached to the target line. In the child version, feedback was given after every trial. If the participant responds correctly, he heard “WooHoo” from the fish but if the response was inaccurate or not within the 1700 ms deadline, a low tone was played. For the bimodal modification, both versions were slightly altered so that the negative feedback tone was replaced with a buzzer sound as to not confuse the children about the purpose of the auditory warning cues. The instructions from Experiment 1B were included in this experiment but simplified so that the children would understand more readily.

The tone practice program remained similar in content but was expanded to allow for a firmer conception of the differences between the tones for both the adults and children. The first tone practice played each tone once before the participant was required to name the tones, but in the expanded version, the tones were played 5 times each before the testing portion began. In addition to that change, the number of trials was increased from 20 to 24, allowing one extra exposure to each tone.

Results

The results were divided into five sections: preliminary analyses, RT analyses, error rate analyses, network scores with their correlations, and tone practice results. The error rate section was also divided by the modality of the program with results from the Original ANT presented first and the Bimodal ANT results second. All higher-level analyses were followed by pair-wise comparisons with Bonferroni corrections unless otherwise noted.

Preliminary Analyses

Several preliminary analyses were conducted to ensure the normality of the distributions and to explore possible abnormalities in the data set. These analyses include investigation of order effects, practice effects, and possible response biases.

The first analysis consisted of a visual inspection of the number of accurate data points contributed by each participant to each condition as mentioned above. This inspection revealed that two participants, one kindergartener and one second grader, were missing more than 50% of the accurate data points in one or more cells and these participants were excluded from all other data analyses.

While order effects were controlled for by counterbalancing the programs, order was included in some of the ANOVAs to investigate whether some differences did exist in performance depending on the order of the tasks. Some significant main effects of order appeared in the RT and error rate analyses, but after further inspection, these were determined to be practice effects of performing two very similar tasks and getting faster and more accurate over time. In the accuracy of the bimodal version, some interactions of order x flanker, and order x flanker x grade appeared. The difference between the neutral and congruent flanker accuracy drove both interactions in that the neutral flanker was generally less accurate than the congruent flanker with the difference decreasing with increasing age and decreasing with more practice (when participants completed the original version before the bimodal version).

Another way that practice effects were analyzed was by comparing RT performance among the three blocks that made up the non-practice part of the program. In the original version of the ANT, a 3 (block) x 3 (flanker) x 4 (warning) within-subjects ANOVA revealed that there was a significant main effect of block, F (2, 178) = 9.38, $\eta_p^2 = 0.10$, $p < .01$, but there were no significant interactions. This main effect indicated that the last block was significantly faster than the first two blocks. In a similar ANOVA divided by grade, the only group that maintained the significant main effect of block was the second grade, F (2, 38) = 6.78, $\eta_p^2 = 0.26$, $p < .01$. This main effect was indicative of the third block being significantly faster than the first block showing the beneficial result of practice. In the bimodal version, there was also a significant main effect of block, F (2, 178) = 5.03, $\eta_p^2 = 0.05$, $p < .01$; but no significant main effects of block when analyzed by grade. The main effect of block indicated that for the bimodal version, the third block was significantly faster than the first block.

The next set of analyses followed up on analyses performed by Rueda et al. (2004) for possible response biases. Response biases could occur in two different manners: responses differing based on whether the target appears above or below the fixation point and responses differing based on the direction the target faces, reflected in the response time of the hand that pressed the corresponding button. The difference between top versus bottom targets was analyzed with a 2 (location of target) x 3 (flanker) x 4 (warning) ANOVA for both the original and bimodal version's RT data. No significant main effects or interactions were found for the location variable in the original version. However, in the bimodal version, a significant main effect of location, F (1, 89) = 4.94, $\eta_p^2 = 0.05$, $p < .05$, appeared but represented a difference of 6.88 ms (*SE* = 0.03) in favor of performance for above-the-fixation targets, which while statistically significant is not practically significant. The results of the analysis for the original ANT replicated the findings of Rueda et al. (2004). Therefore, this variable was not included in further analyses.

However, when the RT data for the original version was analyzed with a 2 (direction of target) x 4 (grade) x 3 (flanker) x 4 (warning) within-subjects ANOVA, a significant main effect and some significant interactions of direction were found. The significant main effect of direction,

F (1, 89) = 36.04, $\eta_p^2 = 0.29$, $p < .01$, showed that the right facing targets (in other words responses made with the right hand) were responded to significantly faster than targets facing the left. The difference was 28.31 ms (*SE* = 4.72). This main effect was qualified by several significant interactions: direction x grade, F (3, 89) = 4.15, $\eta_p^2 = 0.12$, $p < .01$; direction x flanker, F (2, 178) = 6.24, $\eta_p^2 = 0.07$, $p < .01$; direction x flanker x warning, F (6, 534) = 2.45, $\eta_p^2 = 0.03$, $p < .05$; and direction x flanker x warning x grade, F (18, 534) = 1.86, $\eta_p^2 = 0.06$, $p < .05$. The interaction of direction x grade showed that the differences in RT performance related to the direction of the target are much greater in the kindergarteners and second graders than the fourth graders and adults. The interaction of direction x flanker indicated that there was a difference in the reaction time to congruent flankers but that the other types did not differ significantly and a paired samples *t*-test confirmed that the left facing congruent condition was significantly slower than the right facing congruent condition, t (92) = 4.46, $p < .01$. The finding of a main effect of target direction replicated Mezzacappa (2004) but not Reuda et al. (2004).

To better understand the higher-level interactions, separate 2 (direction) x 3 (flanker) x 4 (warning) ANOVAs were performed for each grade group. The only two grades that still had main effects of direction were kindergarten, F (1, 18) = 10.77, $\eta_p^2 = 0.37$, $p < .01$, and second grade, F (1, 19) = 18.28, $\eta_p^2 = 0.49$, $p < .01$. For the kindergarten group, the speed differential was 35.91 ms (*SE* = 10.94) with faster performance for the right facing target, and for the second grade group, there was a 50.87 ms difference (*SE* = 11.90) in the same direction. The kindergarten group also had a significant interaction of direction x flanker, F (2, 36) = 3.37, $\eta_p^2 = 0.16$, $p < .05$. This interaction matched the same one for the larger scale ANOVA, with the neutral and congruent flankers being very similar when the target faced right but the neutral condition was much faster than the congruent condition when the target faced left. All of the significant differences related to the direction of the flanker did not replicate the findings of Rueda et al. (2004) where no significant differences were found.

In the bimodal version, there was also a significant main effect of direction, F (1, 89) = 12.57, $\eta_p^2 = 0.12$, $p < .01$ which was qualified by one significant 3-way interaction, direction x flanker x grade, F (6, 178) = 2.41, $\eta_p^2 = 0.08$, $p < .05$. The difference between right facing targets and left facing targets was somewhat smaller in the bimodal version: 17.49 ms (*SE* = 4.93) with participants responding quicker to the right facing targets. The interaction was driven by both the congruent and neutral flanker conditions because their relationship (which one was faster and how much difference there was between the two conditions) varied by the grade. This interaction was followed by a 2 (direction) x 3 (flanker) within-subjects ANOVA within each grade. Kindergarteners had a significant interaction of direction x flanker, F (2, 36) = 3.84, $\eta_p^2 = 0.18$, $p < .05$ but no significant main effect of direction. While the congruent flanker times were not different based on directionality of the cue, the neutral flanker targets were responded to significantly faster (49.57 ms, *SE* = 15.31) if they faced right than if they were left facing. Second graders had a significant main effect of direction, F (1, 19) = 11.49, $\eta_p^2 = 0.38$, $p < .01$, but no significant interaction. This main effect indicated that when the target faced right, these participants were 35.36 ms (*SE* = 10.44) faster than when the target faced left. Both the fourth grade and adult groups failed to meet significance for the main effect or interaction.

To summarize, there were very few overall abnormalities in the data set. The investigation of order effects did indicate that there was a benefit to performance in the second version completed by the participant but this variable had been counterbalanced in the method. The order variable was dropped from further analyses. The practice effects also showed a similar conclusion: performance increased as the task continued. Practice effect variables were also dropped from further analyses. Response biases were found to some extent: performance was slightly faster in the bimodal version for targets appearing above the fixation point and the younger children were faster in pressing the key when the target faced right than left. The flanker variable was included in most of the interactions with the differences lying in the relationship between the neutral and congruent flankers. Since the network scores are based on the relationship between the congruent and incongruent flanker conditions, the relationship between the neutral and congruent conditions is less meaningful to the task itself. In that vein, the response biases variables were not included in further analyses.

RT Analyses

The first analysis that was completed was a 2 (version: original, bimodal) x 4 (age group: kindergarten, second grade, fourth grade, and adults) x 3 (flanker: neutral, incongruent, congruent) x 4 (warning: middle or center, double or chord, spatial, and no warning) mixed ANOVA on the means of the median response times on all of the accurate trials. The results can be seen in Table 4.

Table 4. Analysis of Variance for Response Time Performance for Experiment 2

Source	*df*	*F*	η_p^2	*p*
		Between subjects		
Grade (G)	3	211.13**	0.88	0.01
G error	89	(129317.97)		
		Within-subjects		
Version (V)	1	14.81**	0.14	0.01
Flanker (F)	2	217.10**	0.71	0.01
Warning (W)	3	231.02**	0.72	0.01
V error	89	(65810.69)		

(Table 4 cont.)

F error	178	(7214.48)		
W error	267	(4919.50)		
G x V	3	0.50	0.02	0.68
G x F	6	0.60	0.02	0.70
G x W	9	7.10**	0.19	0.01
V x F	2	1.55	0.04	0.22
V x F error	178	(3387.46)		
V x W	3	9.02**	0.24	0.01
V x W error	267	(4102.82)		
F x W	6	1.61	0.11	0.15
F x W error	534	(2892.77)		
V x G x F	6	0.90	0.03	0.49
V x G x W	9	1.02	0.03	0.42
G x F x W	18	0.84	0.05	0.64
V x F x W	6	2.41**	0.14	0.03
V x F x W error	534	(2978.90)		
G x V x F x W	18	0.76	0.05	0.73

Note: Numbers in parentheses represent the mean square error.
* This indicates significance at $p < 0.05$ level.
** This indicates significance at $p < 0.01$ level.

The main effects will be discussed first followed by the implications of the significant interactions. The main effect of version indicated that the performance in the bimodal version was significantly slower than the original version. The main effect of grade indicated that all groups were significantly different with the kindergarteners as the slowest, then the second graders, and then the fourth graders, with the adults performing the fastest. The pattern of speed can be seen in the scales of Figures 7-14, which were organized by the version of the task (original presented first) and then by grade group in descending order. The main effect of flanker indicated all of the flanker types were significantly different with the performance on incongruent flankers being slowest, the congruent flanker being in the middle, and the neutral flanker performance being the fastest. The main effect of warning indicated that the no warning condition had the slowest performance, the center/middle cue and the double/chord cue are in the middle but not different from each other and the spatial cue had the fastest performance. However, the main effects were qualified by 2 two-way interactions and 1 three-way interaction. These interactions were explored by collapsing across the variable(s) not included in the interaction.

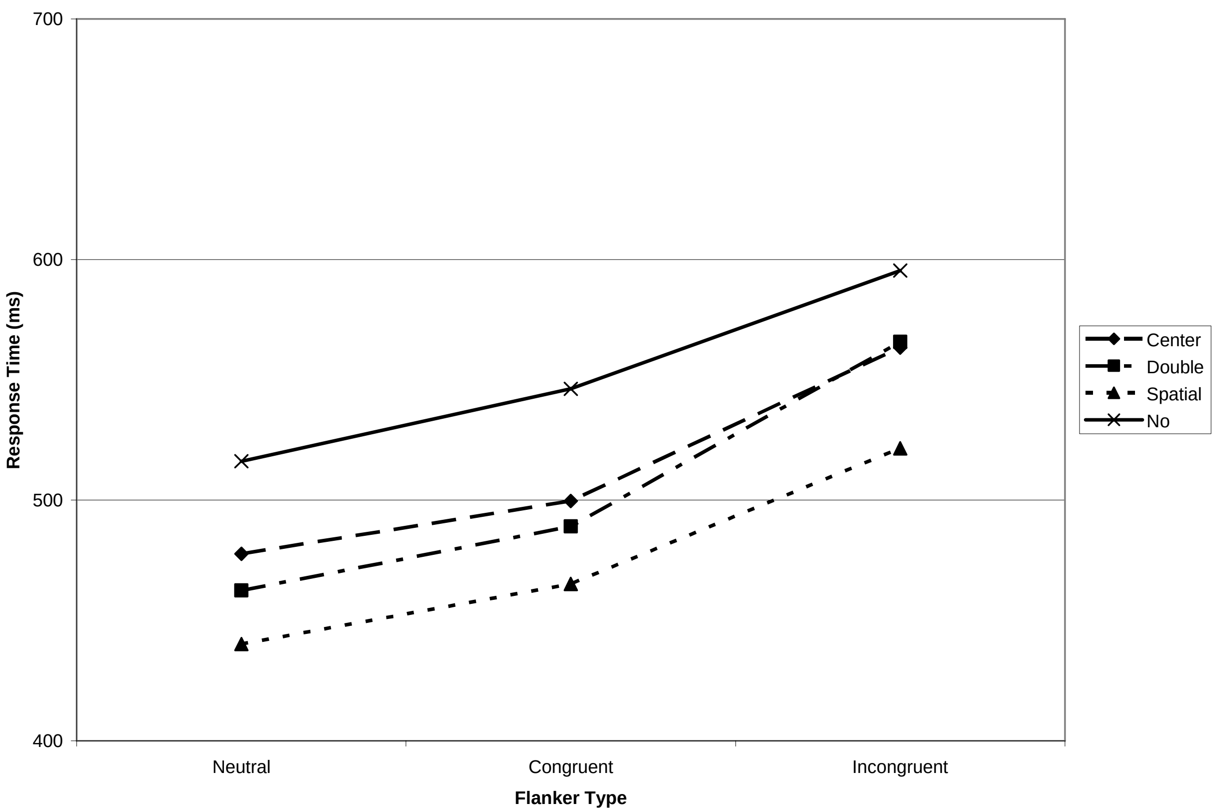

Figure 7. Mean of median response times for Adults in the Original ANT in Experiment 2

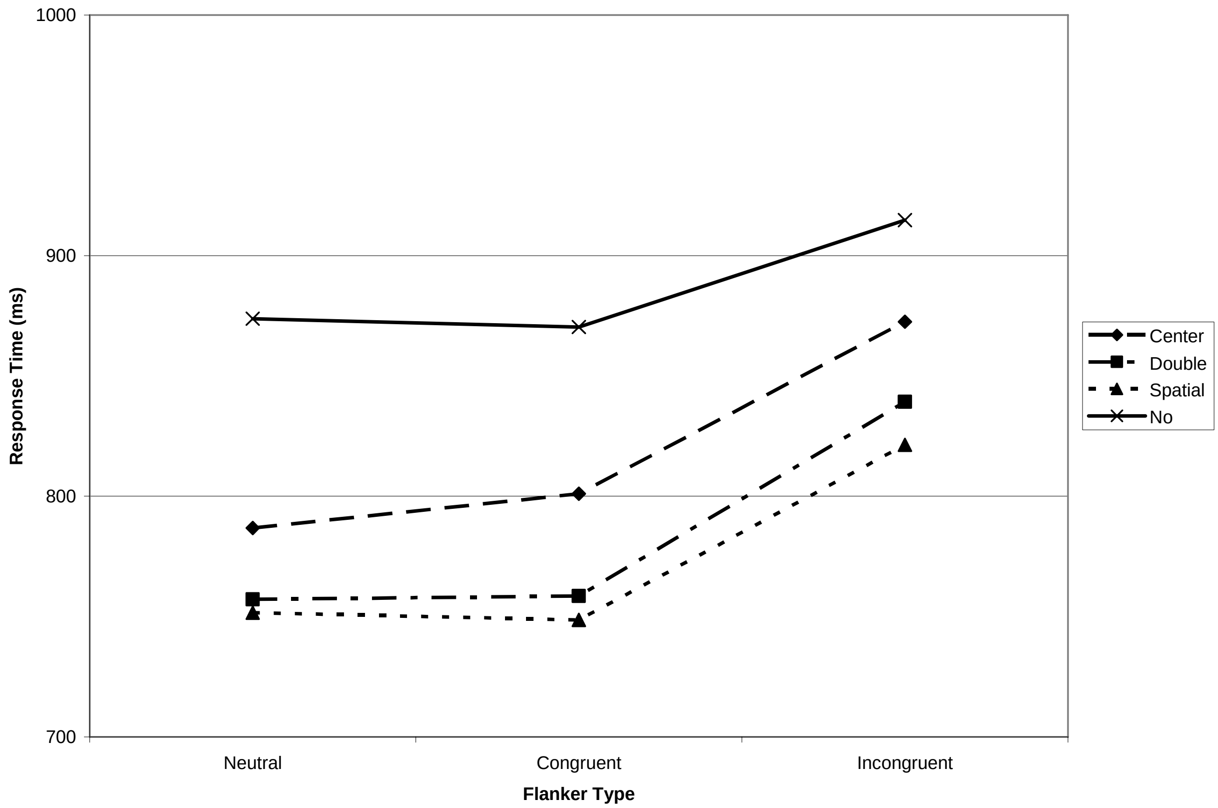

Figure 8. Mean of median response times for Fourth Grade in the Original ANT in Experiment 2

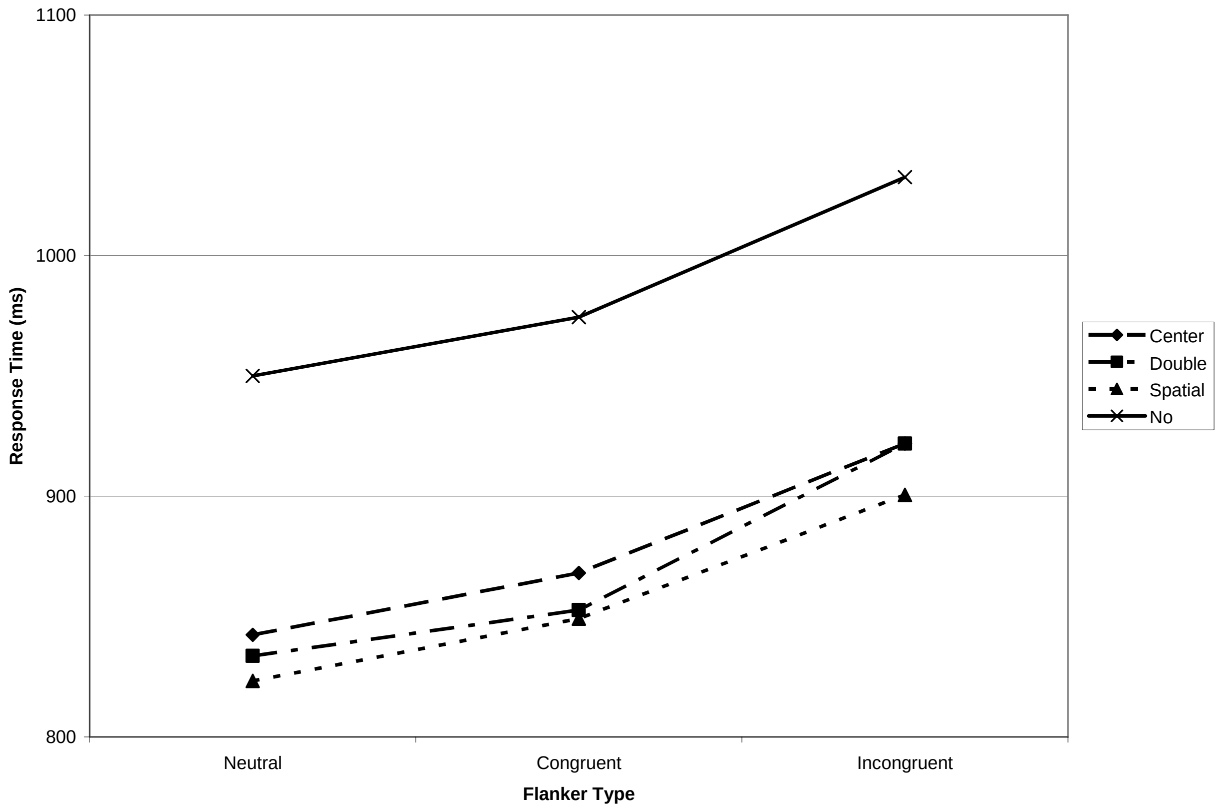

Figure 9. Mean of median response times for Second Grade in the Original ANT in Experiment 2

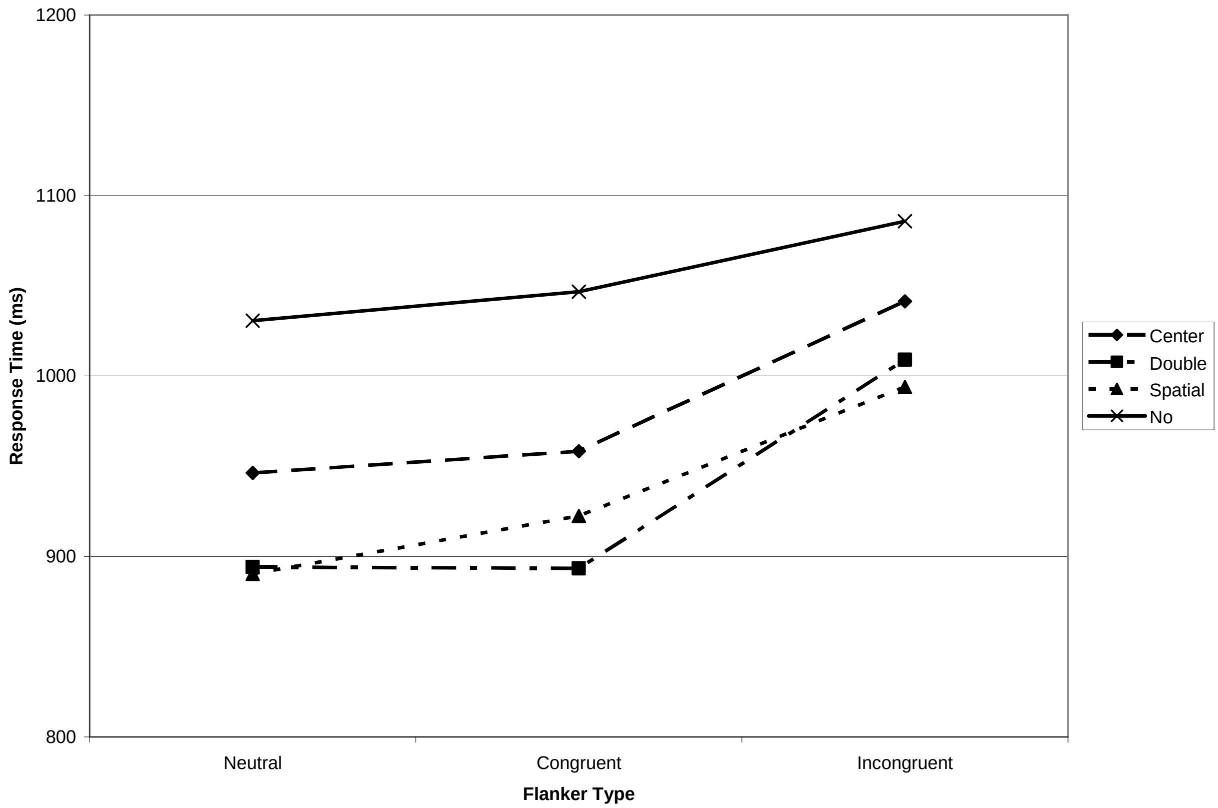

Figure 10. Mean of median response times for Kindergarten in the Original ANT in Experiment 2

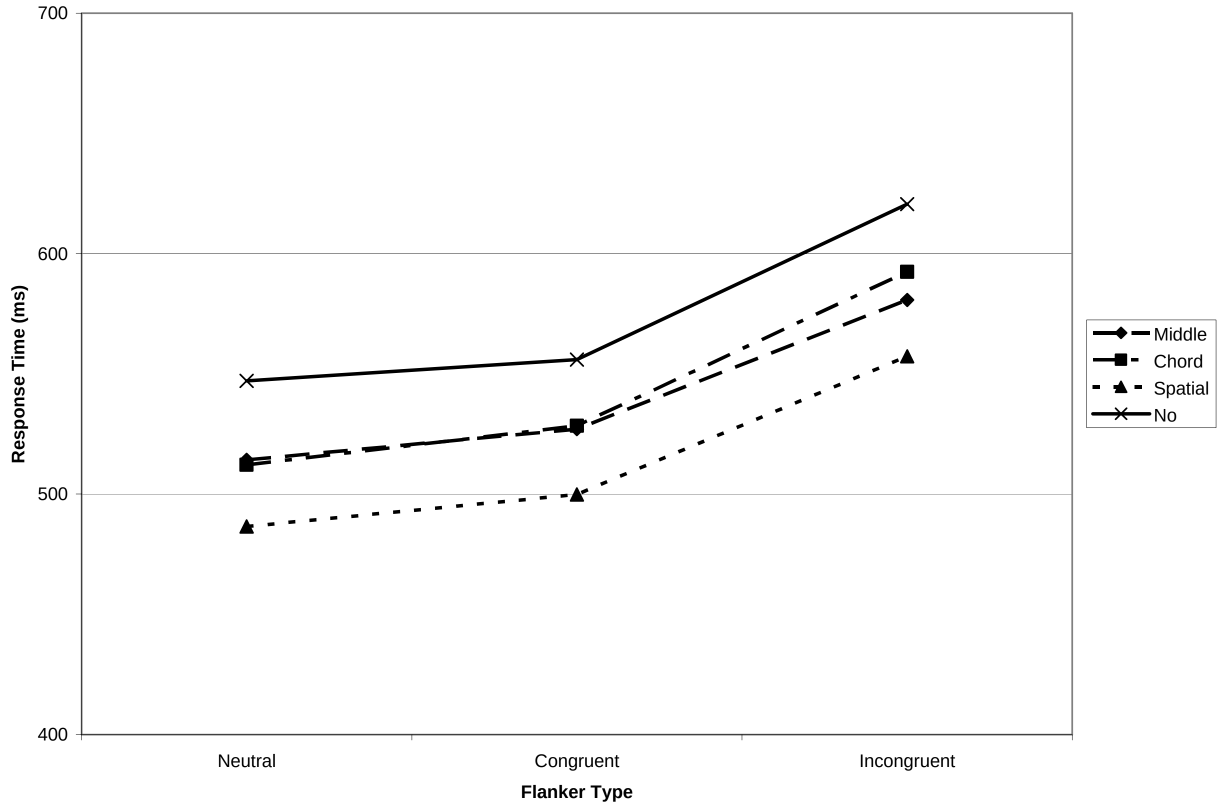

Figure 11. Mean of median response times for Adults in the Bimodal ANT in Experiment 2

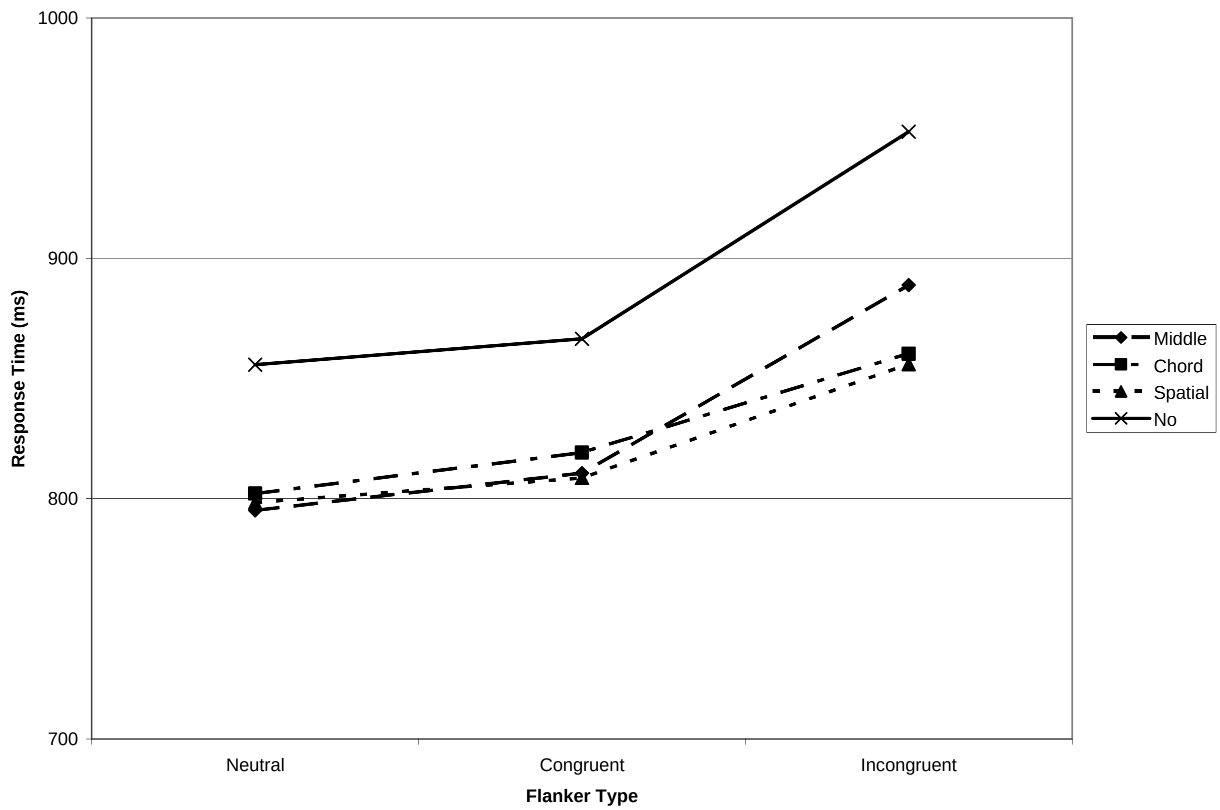

Figure 12. Mean of median response times for Fourth Grade in the Bimodal ANT in Experiment 2

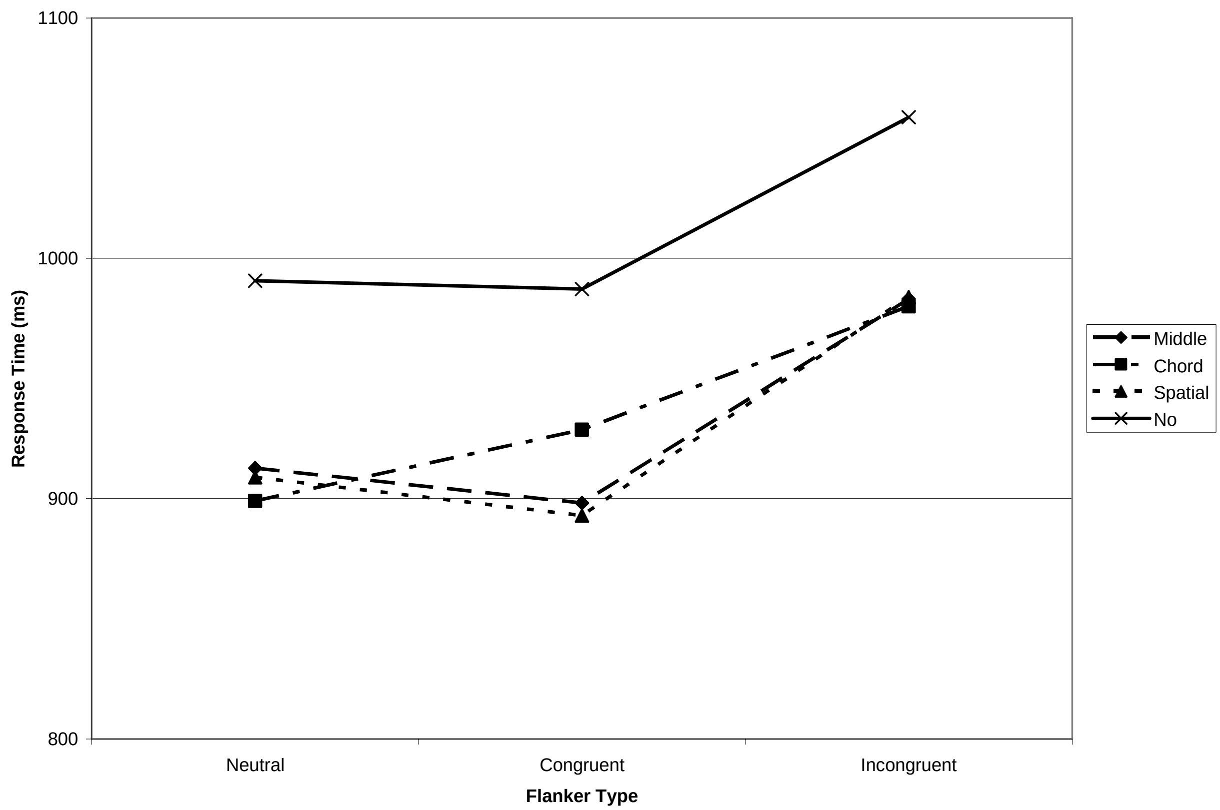

Figure 13. Mean of median response times for Second Grade in the Bimodal ANT in Experiment 2

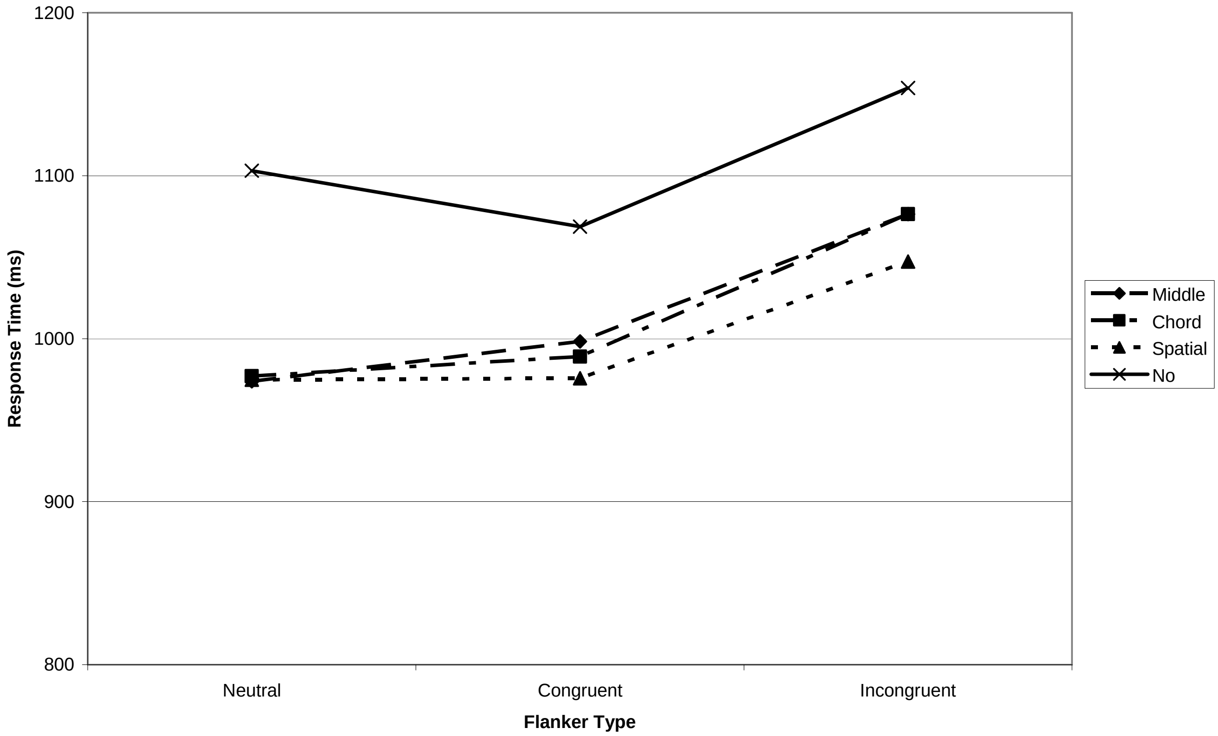

Figure 14. Mean of median response times for Kindergarten in the Bimodal ANT in Experiment 2

After splitting the data set by grade, one-way ANOVAs collapsed across version were completed for the warning variable. Each grade had a significant main effect of warning, which was followed by the pair-wise comparisons of the warning conditions for each grade. For each of the grades, the no warning condition was significantly slower than all others. In the kindergarten and second grade groups, the center/middle, double/chord, and spatial did not differ significantly. In the fourth grade group, the center/middle cue was significantly slower than the spatial cue, and the double/chord cue did not differ from the center/middle or spatial cues. In the adult group, the middle/center and double/chord cue did not differ significantly and the spatial cue was significantly faster than the other cues.

After splitting the data set by version, one-way ANOVAs on the warning variable were utilized to explore the version x warning interaction. The pair-wise comparisons showed that in the original version, all of the warnings differed significantly with spatial being the fastest, double being the next fastest, then the center cue, and finally the no cue condition was the slowest. However, in the bimodal version, the pattern was the same but the chord and middle conditions did not differ significantly.

With the data set split by version, a 3 (flanker) x 4 (warning) within-subjects ANOVA was completed. This ANOVA revealed that while both versions had main effects of flanker and warning, only the original version had a significant interaction of flanker x warning, F (6, 552) = 2.93, $\eta_p^2 = 0.03$, $p < .05$. This was followed by 4 one-way ANOVAs for the specific conditions of the warning, for instance, comparing the congruent center, incongruent center, and neutral center conditions. In these analyses, the incongruent flanker condition was always the slowest for all warning conditions. The no warning conditions and spatial conditions differed significantly for all of the flanker conditions with the neutral condition as the fastest. To contrast, the center and double conditions did not differ significantly for the congruent or neutral conditions. This was indicative of the fact that the more extreme warning conditions (spatial and no warning) and the most extreme flanker condition (incongruent) had the greatest distinction across other conditions but the intermediate conditions had less distinctiveness across each other.

Error Rate Analysis

The scoring reported by Reuda et al. (2004) for this program included two different types of errors which were combined to create the error rate. These two errors consist of an incorrect button press and a no response error. When no response is entered before the 1700 ms from the time the target appears, the trial is "timed out." Table 5 shows the average number of times for each participant that each type of error was made in the two versions. For the kindergarten group as a whole, 66.26% percent of total errors in the original version were due to not pressing a key before the 1700 ms had elapsed, and the percentage was 65.85% in the bimodal version. For the second grade, no response errors occurred in 55.83% of the total errors in the original version and 64.73% in the bimodal version. For the fourth grade, no response errors made up 54.39% of total errors in the original version and 52.31% in the bimodal version. The adults had very different results: in the original version only 10.53% of errors were due to no responses, and in the bimodal version, 4.88% of total errors. These results indicate that the 1700 ms time limit for responses may be too brief for children of these ages. Due to this finding, the accuracy will be discussed in terms of the commission (wrong key press) errors and the omission (timed-out) errors. This manner of evaluating the accuracy replicated the manner utilized by Mezzacappa (2004) in his study of the ANT.

Table 5. Mean number per participant of types of errors by version and grade (*SD* in parentheses)

	Original ANT		Bimodal ANT	
	Button Press	Time Out	Button Press	Time Out
Kindergarten	4.42 (1.87)	8.68 (7.46)	7.33 (7.22)	14.14 (11.14)
2nd Grade	2.79 (2.39)	3.53 (3.78)	3.76 (5.47)	6.90 (6.22)
4th Grade	1.37 (1.16)	1.63 (1.98)	1.55 (1.61)	1.70 (2.13)
Adult	1.62 (1.28)	0.19 (0.58)	1.86 (1.20)	0.10 (0.30)

A 2 (version) x 3 (flanker) x 4 (warning) x 4 (grade) mixed ANOVA was performed for the percentage rate of errors in which the wrong key was pressed (Commission errors, see Table 6). The mean percentages for both original and bimodal version with each condition by grade are in Table 7. This ANOVA revealed significant main effects of grade, version, and flanker variables. The main effect of grade indicated that the kindergarteners had the highest error rate (M = 3.91, SE

= 0.38), the second graders had the next highest error rate (*M* = 2.17, *SE* = 0.37), and the fourth graders and adults did not differ significantly with the lowest error rates (*M* = 0.86, *SE* = 0.35, *M* = 0.82, *SE* = 0.30, respectively). The main effect of version simply indicated that there were more errors in the bimodal version (*M* = 2.27, *SE* = 0.30) than the original version (*M* = 1.61, *SE* = 0.12). The main effect of flanker showed that the incongruent condition had many significantly more commission errors (*M* = 2.82, *SE* = 0.25) than the neutral and congruent conditions (*M* = 1.72, *SE* = 0.18, *M* = 1.28, *SE* = 0.20, respectively), which did not differ. However, these main effects were qualified by three significant interactions: grade x flanker, version x warning, and version x warning x grade.

Table 6. Analysis of Variance for Commission Error Rates for Experiment 2

Source	*df*	*F*	η_p^2	*p*
	Between subjects			
Grade (G)	3	16.70**	0.36	0.01
G error	89	(65.81)		
	Within-subjects			
Version (V)	1	5.09**	0.05	0.03
Flanker (F)	2	28.02**	0.24	0.01
Warning (W)	3	0.47	0.01	0.70
V error	89	(44.79)		
F error	178	(16.15)		
W error	267	(13.15)		
G x V	3	1.53	0.05	0.21
G x F	6	6.55**	0.18	0.01
G x W	9	1.40	0.05	0.19

(Table 6 cont.)

V x F	2	0.78	0.01	0.46
V x F error	178	(16.61)		
V x W	3	2.97*	0.03	0.03
V x W error	267	(13.15)		
F x W	6	1.20	0.01	0.30
F x W error	534	(13.33)		
V x G x F	6	1.87	0.06	0.09
V x G x W	9	2.88**	0.09	0.01
G x F x W	18	0.81	0.03	0.69
V x F x W	6	0.79	0.01	0.58
V x F x W error	534	(14.86)		
G x V x F x W	18	0.60	0.02	0.90

Note: Numbers in parentheses represent the mean square error.
* This indicates significance at $p < 0.05$ level.
** This indicates significance at $p < 0.01$ level.

Table 7. Percentage of Commission Error Rate (with *SD* in parentheses)

Original				
Kindergarten				
	Center	Double	Spatial	No
Neutral	0.88 (2.63)	2.19 (3.77)	0.88 (2.63)	3.51 (5.06)
Congruent	2.19 (4.68)	3.07 (4.98)	2.63 (3.98)	3.95 (5.10)
Incongruent	5.26 (6.34)	5.26 (6.34)	3.95 (5.81)	3.95 (5.10)
Second Grade				
	Center	Double	Spatial	No
Neutral	1.67 (4.36)	0.83 (2.56)	3.33 (4.19)	2.50 (7.69)
Congruent	0.00 (0.00)	1.25 (3.05)	0.83 (2.56)	0.83 (2.56)
Incongruent	3.33 (4.99)	1.25 (3.05)	3.33 (4.99)	2.92 (5.59)

(Table 7 cont.)

Fourth Grade

	Center	Double	Spatial	No
Neutral	0.72 (2.40)	0.72 (2.40)	0.36 (1.74)	0.72 (2.40)
Congruent	1.09 (2.87)	0.00 (0.00)	1.09 (2.87)	0.00 (0.00)
Incongruent	1.81 (3.51)	0.00 (0.00)	0.36 (1.74)	2.54 (5.29)

Adults

	Center	Double	Spatial	No
Neutral	1.08 (2.84)	0.54 (2.08)	0.27 (1.50)	0.81 (3.30)
Congruent	0.54 (2.08)	0.00 (0.00)	0.27 (1.50)	0.00 (0.00)
Incongruent	1.61 (3.98)	1.88 (4.67)	1.34 (3.79)	0.81 (2.50)

Bimodal

Kindergarten

	Middle	Chord	Spatial	No
Neutral	2.19 (4.68)	5.70 (10.03)	3.95 (5.10)	1.75 (4.46)
Congruent	3.51 (5.77)	4.39 (7.54)	3.95 (8.50)	1.32 (5.74)
Incongruent	7.46 (7.80)	7.46 (7.29)	8.77 (8.99)	6.58 (8.60)

Second Grade

	Middle	Chord	Spatial	No
Neutral	3.75 (8.32)	3.75 (6.33)	1.67 (4.36)	3.75 (8.32)
Congruent	1.25 (3.05)	2.50 (5.47)	0.83 (2.56)	1.67 (5.13)
Incongruent	2.50 (4.76)	2.92 (6.21)	3.33 (9.52)	2.08 (5.97)

Fourth Grade

	Middle	Chord	Spatial	No
Neutral	1.45 (4.09)	2.90 (4.06)	0.00 (0.00)	0.72 (2.40)
Congruent	0.72 (2.40)	1.09 (2.87)	0.00 (0.00)	0.36 (1.74)
Incongruent	1.81 (4.32)	0.72 (2.40)	0.36 (1.74)	1.61 (3.35)

Adults

	Middle	Chord	Spatial	No
Neutral	0.27 (1.50)	0.54 (2.08)	0.54 (2.08)	1.08 (2.84)
Congruent	0.00 (0.00)	0.27 (1.50)	0.27 (1.50)	1.08 (3.56)
Incongruent	1.61 (3.35)	1.08 (2.84)	0.36 (1.74)	1.61 (3.35)

The grade x flanker interaction was followed by 4 one-way ANOVAs on the flanker variable, which showed two significant main effects of flanker. The main effect for the kindergarteners indicated that the incongruent condition had significantly more errors than the neutral and congruent conditions, which did not differ, $F\ (2, 36) = 4.17$, $\eta_p^2 = 0.19$, $p < .03$. In the second grade group, the main effect of flanker indicated that the congruent condition had the fewest errors but the neutral and incongruent conditions did not differ significantly, $F\ (2, 38) = 8.15$, $\eta_p^2 = 0.30$, $p < .01$. However, there was not a significant main effect of flanker for the fourth grade group or the adult group.

The version x warning interaction was more difficult to interpret because of the version x warning x grade interaction that qualified it. No main effect of warning was found for either the original or bimodal versions. But when broken down to the age groups, the fourth grade group for the bimodal version had a significant main effect of the warning variable, $F\ (3, 66) = 4.37$, $\eta_p^2 = 0.17$, $p < .01$, indicative of a significant difference between the spatial cue condition which had the lowest commission error rate and the chord condition which had the highest error rate. The other two conditions, no cue and middle, did not differ significantly from any other condition.

The omission errors provided a much different picture in the 2 (version) x 3 (flanker) x 4 (warning) x 4 (grade) mixed ANOVA that was performed with that data (see Table 8). For mean omission error rates, see Table 9. In this analysis as well, there were significant main effects of grade, version, and flanker, which mirrored the results of the commission error ANOVA but also one for the warning variable. Like the commission error rate analysis, we also found significant interactions of grade x flanker, version x warning, and version x grade x warning. In addition, the grade x version, grade x warning, and version x flanker interactions were also significant. Since so many interactions were significant, this analysis was followed by two 3 (flanker) x 4 (warning) x 4 (grade) ANOVAs for each version which are discussed separately by version.

Table 8. Analysis of Variance for Omission Error Rates for Experiment 2

Source	*df*	*F*	η_p^2	*p*
	Between subjects			
Grade (G)	3	29.67**	0.50	0.01
G error	89	(201.15)		
	Within-subjects			
Version (V)	1	13.93**	0.14	0.01
Flanker (F)	2	12.40**	0.12	0.01
Warning (W)	3	20.72**	0.19	0.01
V error	89	(75.23)		
F error	178	(26.55)		
W error	267	(21.81)		
G x V	3	4.64**	0.14	0.01
G x F	6	4.72**	0.14	0.01
G x W	9	4.81**	0.14	0.01
V x F	2	7.59**	0.08	0.01
V x F error	178	(28.32)		
V x W	3	7.42**	0.08	0.01
V x W error	267	(26.12)		
F x W	6	0.62	0.01	0.71
F x W error	534	(18.94)		
V x G x F	6	2.56*	0.08	0.02

(Table 8 cont.)

V x G x W	9	4.54**	0.13	0.01
G x F x W	18	0.90	0.03	0.58
V x F x W	6	0.44	0.01	0.85
V x F x W error	534	(20.84)		
G x V x F x W	18	1.07	0.04	0.38

Note: Numbers in parentheses represent the mean square error.
* This indicates significance at $p < 0.05$ level.
** This indicates significance at $p < 0.01$ level.

Table 9. Percentage of Omission Error Rate (with *SD* in parentheses)

Original				
Kindergarten				
	Center	Double	Spatial	No
Neutral	7.89 (8.55)	3.51 (6.40)	4.82 (9.34)	6.14 (6.71)
Congruent	7.89 (9.41)	7.02 (11.20)	3.07 (6.34)	6.14 (8.71)
Incongruent	8.33 (9.21)	3.51 (8.01)	6.14 (6.11)	7.89 (8.09)
Second Grade				
	Center	Double	Spatial	No
Neutral	2.92 (4.08)	2.50 (6.11)	2.08 (3.70)	4.58 (5.72)
Congruent	2.08 (3.70)	0.83 (2.56)	2.50 (3.92)	0.83 (2.56)
Incongruent	1.67 (3.42)	4.17 (7.88)	0.42 (1.86)	2.50 (3.92)
Fourth Grade				
	Center	Double	Spatial	No
Neutral	0.36 (1.74)	0.72 (2.40)	0.00 (0.00)	2.54 (4.66)
Congruent	1.45 (3.23)	0.36 (1.74)	0.36 (1.74)	0.72 (2.40)
Incongruent	0.36 (1.74)	0.72 (2.40)	1.81 (3.51)	1.81 (3.51)
Adults				
	Center	Double	Spatial	No
Neutral	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.27 (1.50)
Congruent	0.27 (1.50)	0.00 (0.00)	0.00 (0.00)	0.27 (1.50)
Incongruent	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.27 (1.50)

(Table 9 cont.)

Bimodal				
Kindergarten				
	Middle	Chord	Spatial	No
Neutral	6.58 (11.31)	5.70 (9.64)	5.26 (8.43)	11.84 (10.51)
Congruent	4.82 (10.51)	6.14 (6.71)	7.02 (9.73)	12.28 (14.53)
Incongruent	8.33 (12.42)	11.84 (13.41)	10.96 (14.78)	18.42 (18.13)
Second Grade				
	Middle	Chord	Spatial	No
Neutral	3.33 (6.84)	3.33 (6.84)	4.17 (5.74)	8.33 (12.09)
Congruent	2.08 (4.58)	1.67 (4.36)	2.50 (4.76)	5.00 (6.84)
Incongruent	6.67 (9.97)	4.17 (7.40)	5.83 (7.20)	10.42 (9.70)
Fourth Grade				
	Middle	Chord	Spatial	No
Neutral	1.45 (4.09)	2.90 (4.06)	0.00 (0.00)	0.72 (2.40)
Congruent	0.72 (2.40)	1.67 (4.36)	1.45 (4.09)	1.45 (3.23)
Incongruent	1.45 (3.23)	0.72 (2.40)	1.81 (3.51)	1.45 (3.23)
Adults				
	Middle	Chord	Spatial	No
Neutral	0.27 (1.50)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Congruent	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.27 (1.50)
Incongruent	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)

In the original version, the 3 x 4 x 4 mixed ANOVA revealed significant main effects of grade and warning (see Table 10). The main effect of grade showed that the adult and fourth grade groups did not differ significantly with the lowest omission error rates, the second grade group with slightly more errors still did not differ from the fourth grade group but was significantly different than the other groups, and the kindergarteners had the highest error rate of all of the groups and was significantly different than those groups. The main effect of warning indicated that the no cue condition and center condition had the highest errors and did not differ from each other but were significantly different than the spatial and double cue conditions, which had the lowest errors and also did not differ from each other.

Table 10. Analysis of Variance for Original ANT Omission Rates for Experiment 2

Source	*df*	*F*	η_p^2	*p*
	Between subjects			
Grade (G)	3	20.42**	0.40	0.01
G error	89	(88.13)		
	Within-subjects			
Flanker (F)	2	0.72	0.01	0.49
Warning (W)	3	5.82**	0.06	0.01
F error	178	(12.94)		
W error	267	(15.13)		
G x F	6	1.15	0.04	0.33
G x W	9	2.67**	0.08	0.01
F x W	6	0.94	0.01	0.46
F x W error	534	(14.49)		
G x F x W	18	1.85*	0.06	0.02

Note: Numbers in parentheses represent the mean square error.
* This indicates significance at $p < 0.05$ level.
** This indicates significance at $p < 0.01$ level.

There were two significant interactions, grade x warning and grade x flanker x warning. To better understand these two interactions, four 3 (flanker) x 4 (warning) ANOVAs were performed for each age group (see Table 11). These indicated a significant main effect of warning for both the kindergarten group and the fourth grade group and significant interactions of flanker x warning for the second grade group and the fourth grade group. The main effect of warning indicated in the kindergarten group that there was a significant difference between the center cue, which had the highest error rate and the chord, which had the lowest error rate and the other cue conditions did not vary significantly. In the fourth grade, the main effect of warning was inconclusive due to the finding that there were no significant differences in the pair-wise comparisons. To investigate the interactions in the second and fourth grade groups, 4 one-way ANOVAs were performed for the warning variable to find differences in the flanker conditions. In the spatial condition, the fourth grade group showed significant main effect of flanker type but the follow-up pair-wise comparisons failed to show any significant differences, F (4, 44) = 3.30, $\eta_p^2 = 0.13$, $p < .05$. In the no cue condition, the second grade group showed a significant main effect of flanker type, which indicated that the neutral condition had the highest omission error rate and the congruent had the lowest error rate, F (2, 38) = 4.09, $\eta_p^2 = 0.18$, $p < .03$.

Table 11. Analysis of Variance for Original ANT Omission Rates by Grade

Kindergarten					Second Grade				
Source	*df*	*F*	η_p^2	*p*	Source	*df*	*F*	η_p^2	*p*
		Within-subjects					Within-subjects		
Flanker (F)	2	0.48	0.03	0.63	Flanker (F)	2	1.51	0.07	0.23
Warning (W)	3	3.07*	0.15	0.04	Warning (W)	3	1.08	0.05	0.36
F error	36	(30.70)			F error	38	(21.44)		
W error	54	(50.63)			W error	57	(15.28)		
F x W	6	0.88	0.05	0.51	F x W	6	2.61*	0.12	0.02
F x W error	108	(48.83)			F x W error	114	(12.85)		

(Table 11 cont.)

Fourth Grade

Source	*df*	*F*	η_p^2	*p*
	Within-subjects			
Flanker (F)	2	0.60	0.03	0.55
Warning (W)	3	3.49*	0.14	0.02
F error	44	(7.94)		
W error	66	(5.07)		
F x W	6	2.25*	0.09	0.04
F x W error	132	(6.76)		

Adults

Source	*df*	*F*	η_p^2	*p*
	Within-subjects			
Flanker (F)	2	0.33	0.01	0.72
Warning (W)	3	1.35	0.04	0.26
F error	60	(0.57)		
W error	90	(1.11)		
F x W	6	0.33	0.01	0.92
F x W error	180	(0.57)		

Note: Numbers in parentheses represent the mean square error.
* This indicates significance at $p < 0.05$ level.
** This indicates significance at $p < 0.01$ level.

In the bimodal version, the 3 x 4 x 4 mixed ANOVA revealed significant main effects of grade, flanker, and warning qualified by two significant interactions, grade x flanker and grade x warning (see Table 12). The main effect of grade indicated that error rate decreased as age increased with the kindergarteners having the highest omission error rate, next the second graders, but the fourth graders and adults did not differ with the lowest error rates. The main effect of flanker revealed that the incongruent condition had the highest error rates and that the neutral and congruent conditions did not differ significantly. The main effect of warning revealed that the no cue condition had the highest level of omission errors but the other three conditions did not differ. The interaction of grade x flanker was investigated with one-way ANOVAs for the flanker variable separated by grade. These ANOVAs revealed that only the kindergarteners and second graders had significant differences. In the kindergartener group, the significant difference occurred between the neutral condition with the lowest errors and the incongruent condition with the highest errors, F (2, 36) = 3.80, $\eta_p^2 = 0.17$, $p < .03$. The congruent condition only had a slightly higher error rate than the neutral condition but was not significantly different than either of the other two conditions. In the second graders, the congruent condition had significantly fewer errors than either the neutral or incongruent conditions, F (2, 38) = 8.96, $\eta_p^2 = 0.32$, $p < .01$. The grade x warning interaction was investigated with one-way ANOVAs for the warning variable by grade. Also, only the kindergarten and second grade groups showed significant differences. The kindergarten group showed a significant difference between the no cue with the highest error rates than the middle and spatial cue conditions with the lowest error rates, F (3, 54) = 6.15, $\eta_p^2 = 0.26$, $p < .01$. The chord condition did not differ from any other condition. In the second graders, the no cue condition also has the highest error rate but it differs significantly from the chord and middle conditions and the spatial does not differ from any other conditions, F (3, 57) = 6.46, $\eta_p^2 = 0.25$, $p < .01$.

Table 12. Analysis of Variance for Bimodal ANT Omission Rate for Experiment 2

Source	*df*	*F*	η_p^2	*p*
	Between subjects			
Grade (G)	3	23.99**	0.45	0.01
G error	89	(188.25)		
	Within-subjects			
Flanker (F)	2	12.76**	0.13	0.01
Warning (W)	3	17.00**	0.13	0.01
F error	178	(41.92)		
W error	267	(32.80)		
G x F	6	4.36**	0.13	0.01
G x W	9	5.58**	0.16	0.01

(Table 12 cont.)

F x W	6	0.29	0.00	0.94
F x W error	534	(25.29)		
G x F x W	18	0.50	0.02	0.96

Note: Numbers in parentheses represent the mean square error.
* This indicates significance at $p < 0.05$ level.
** This indicates significance at $p < 0.01$ level.

Network Scores

The network scores for the executive control network, the orienting network, and the alerting network are presented in Figures 15, 16, and 17, respectively. The original version network scores replicated those of Rueda et al. (2004) with one exception. The second grade group's original ANT orienting network score was much lower than previous findings and is mirrored in how low the bimodal ANT orienting score was for the same group as compared to the other age groups. One-way ANOVAs were performed on the network scores to see if there were significant grade differences. The only network that had a significant grade difference was the alerting network. The alerting score for the adults was significantly lower than all of the child group scores in the original version, $F\ (3, 89) = 10.68$, $p < .01$, but the adults only had significantly lower scores than the kindergartener group in the bimodal version, $F\ (3, 89) = 5.09$, $p < .01$.

One interesting artifact of utilizing these types of difference scores developmentally is that within a grade higher scores for both orienting and alerting networks are superior, but between grades, lower scores are ideal because the variation in overall response times is decreased, such as seen in the adult group, leaving smaller differences between even the most distinct conditions.

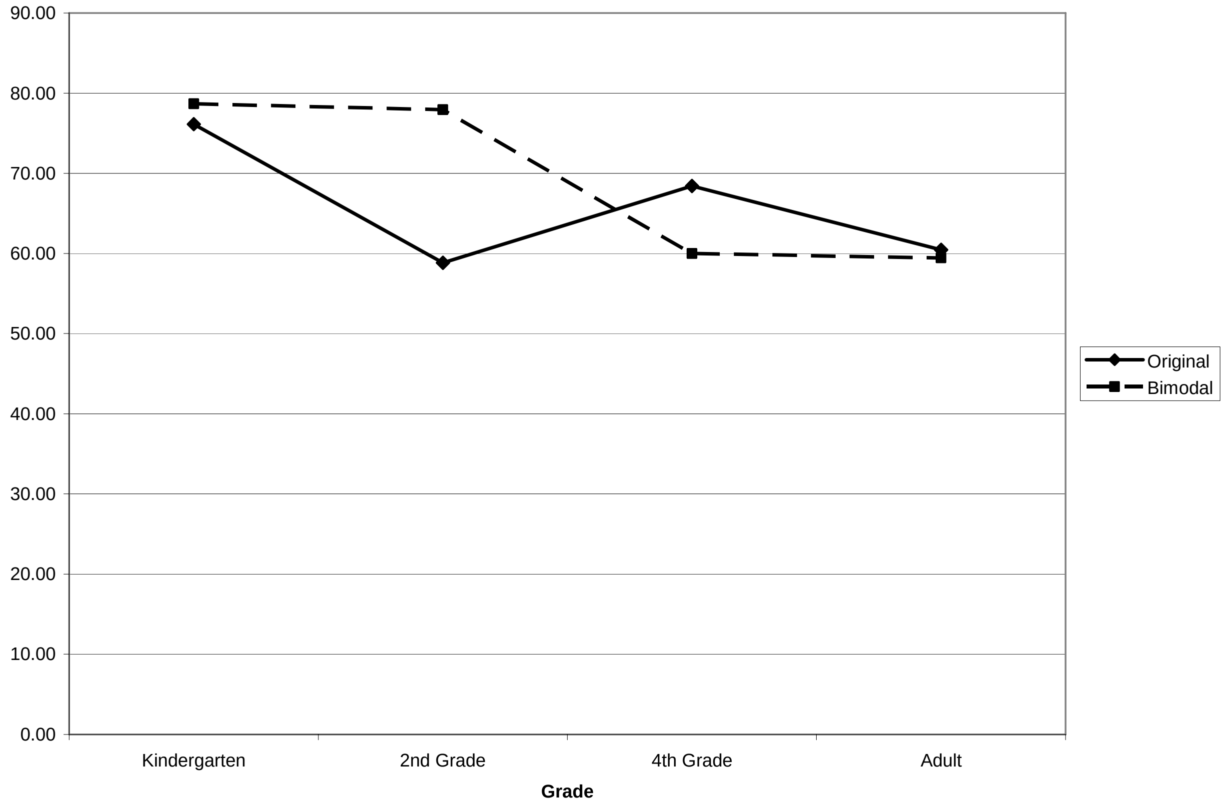

Figure 15. Executive Control Difference Score by Grade in Experiment 2

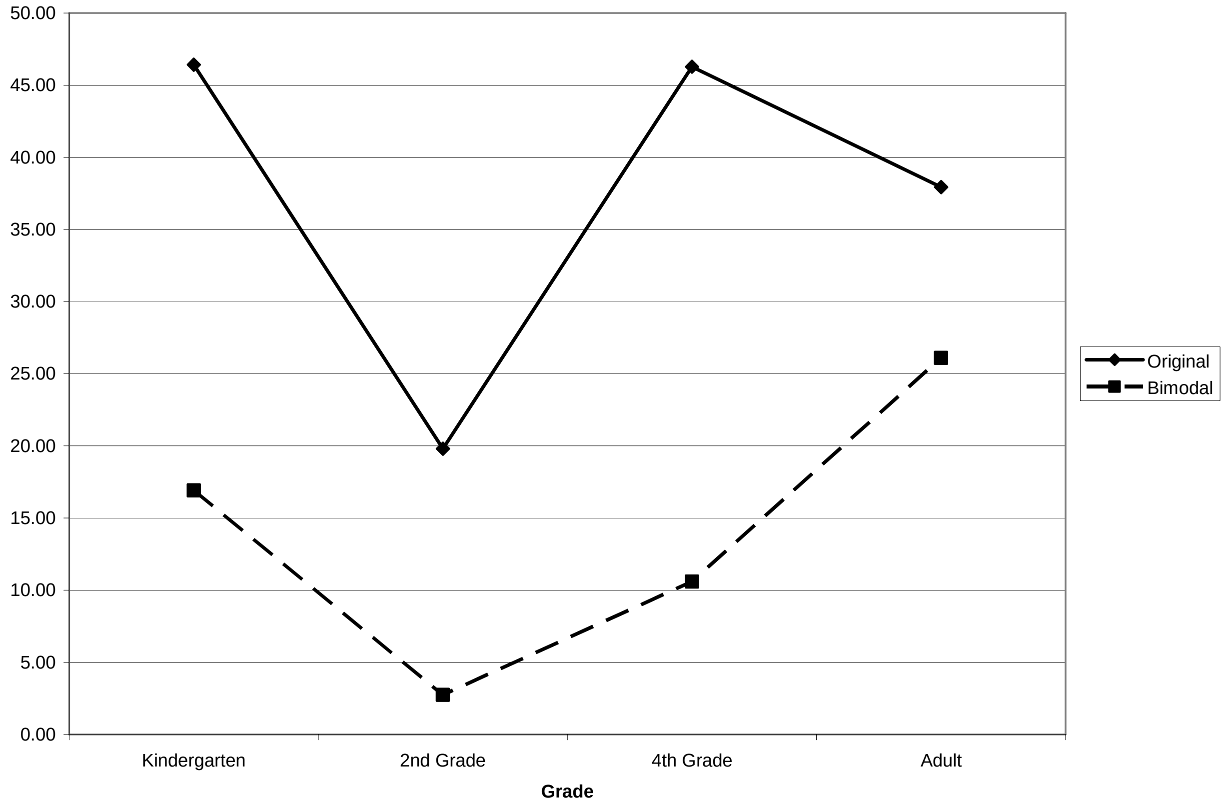

Figure 16. Orienting Network Difference Score by Grade in Experiment 2

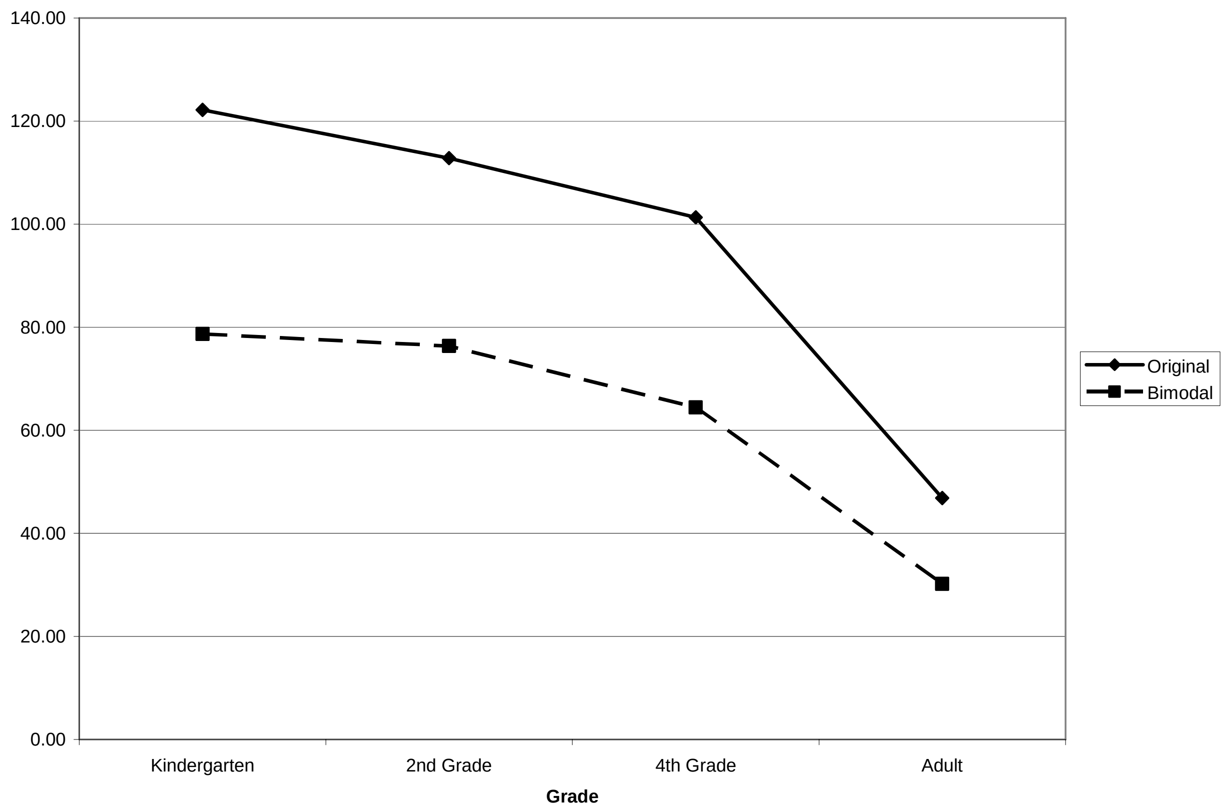

Figure 17. Alerting Network Difference Score by Grade in Experiment 2

This creates unusual patterns in a graph because it appears that kindergarteners have more superior alerting networks, for example, than the adults. To attempt to correct this visual illusion and the address issues of variability within the grades, proportion scores were also created to use in comparison. These scores consisted of (mean of all incongruent trials – mean of all congruent trials) / mean of all congruent trials for executive control (see Figure 18), (mean of all center/middle trials – mean of all spatial trials) / mean of all center/middle trials for orienting network (see Figure 19), and (mean of all no warning trials – mean of all double/chord trials) / mean of all no warning trials for the alerting network (see Figure 20). One obvious difference between the two types of scores is that the scores increase generally with age rather than decrease, with the exception of the alerting score, which decreases in both network calculations. One-way ANOVAs were also calculated for all of these network scores in terms of grade differences. In the original version, the executive control score was significantly lower in the second grade group than the adult group, $F(3, 89) = 3.46$, $p < .05$ and the orienting score showed the same pattern of significant difference, $F(3, 89) = 5.15$, $p < .01$. In the bimodal version, the orienting score showed a similar pattern, being significantly lower in the second grade group than in the adult group, $F(3, 89) = 3.80$, $p < .05$. The executive control network was also significant in the bimodal version but in this version, the fourth grade's score was significantly lower than the adult group's score, $F(3, 89) = 2.97$, $p < .05$.

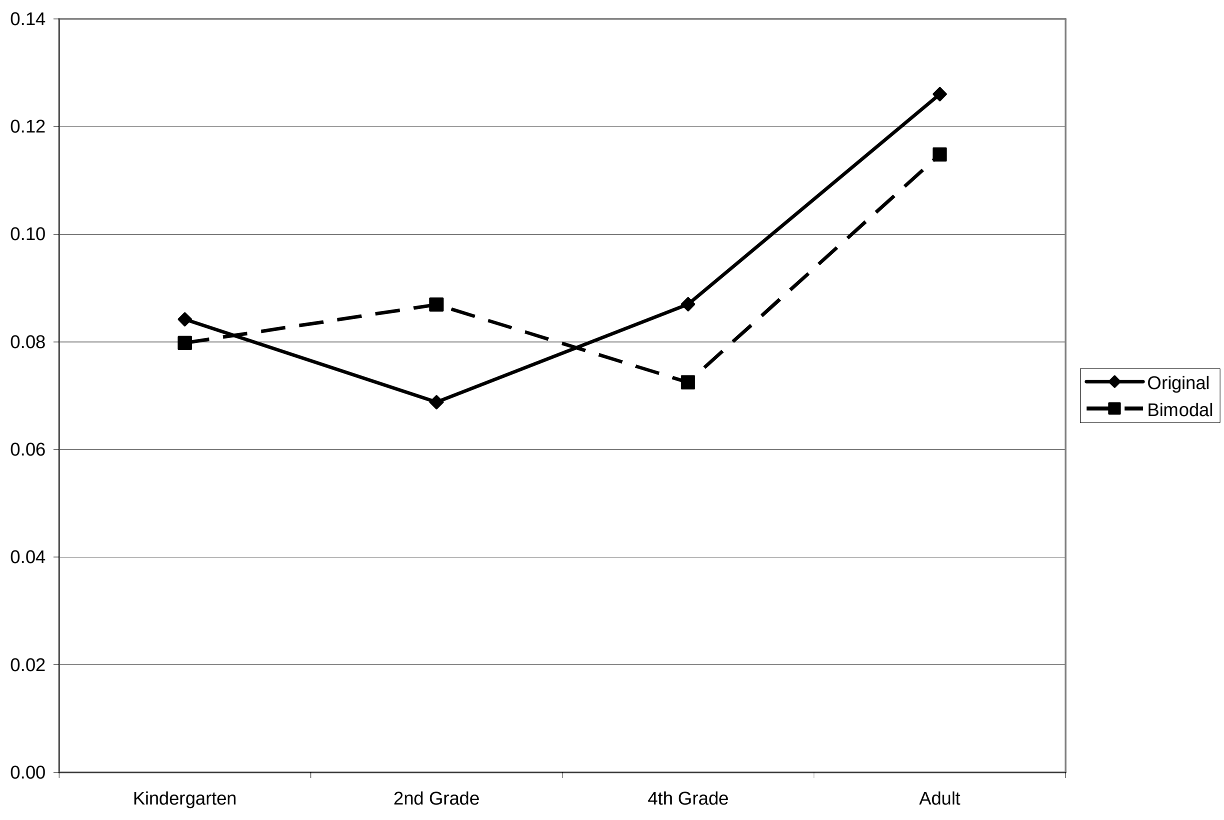

Figure 18. Executive Control Proportion Score by Grade in Experiment 2

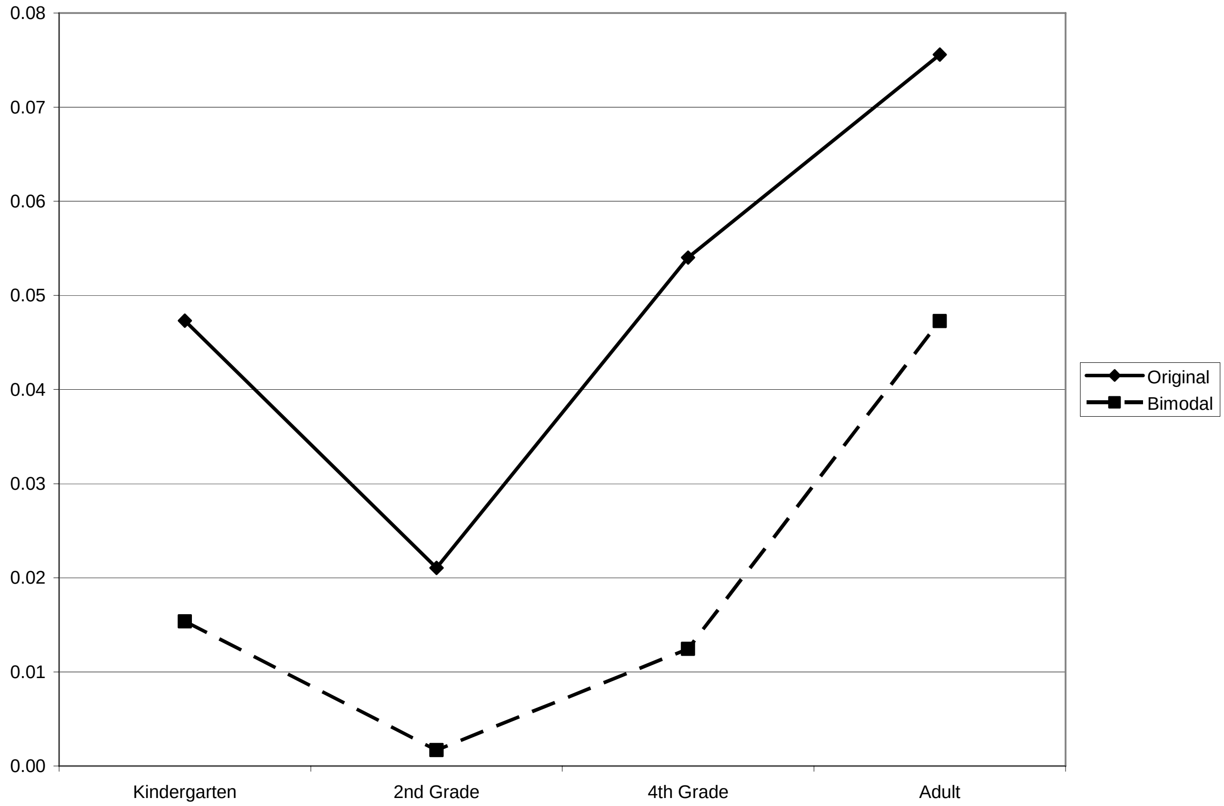

Figure 19. Orienting Network Proportion Score by Grade in Experiment 2

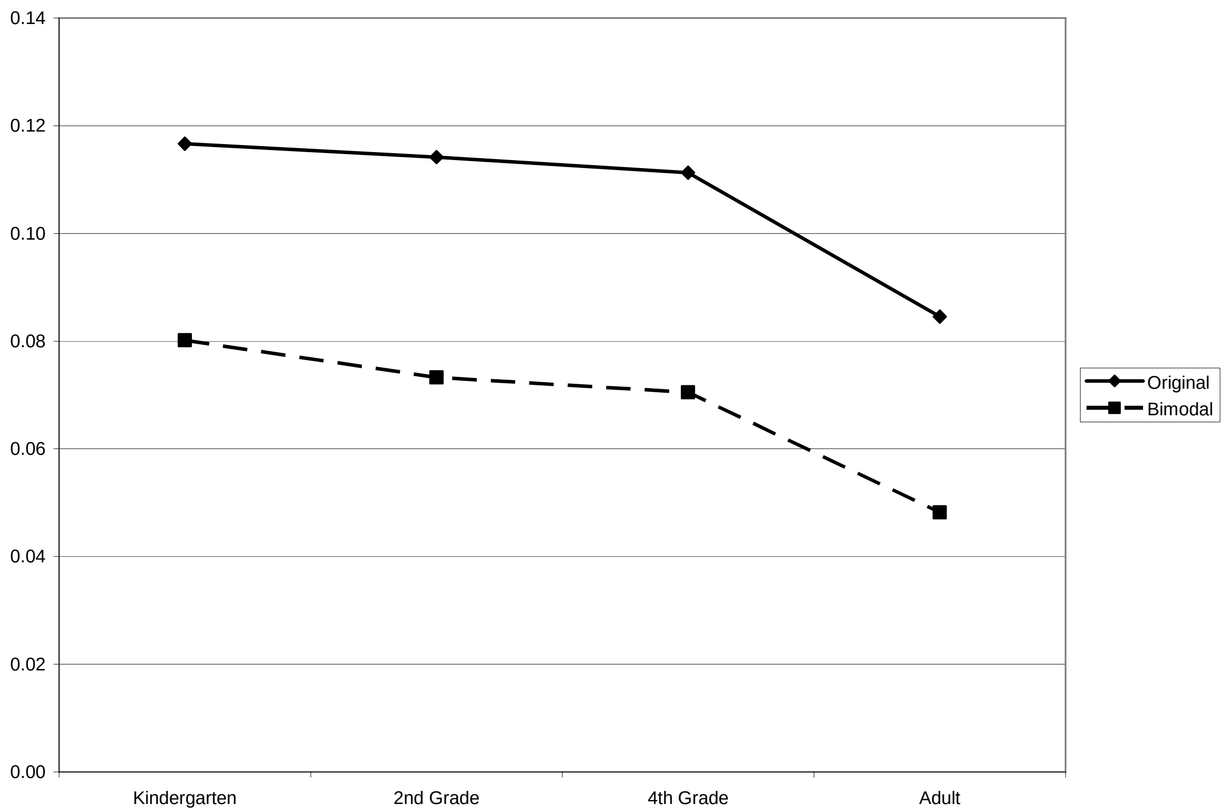

Figure 20. Alerting Network Proportion Score by Grade in Experiment 2

The correlations for the network scores can be seen in Table 13 for the difference scores and Table 14 for the proportion scores. Table 15 has the correlations for each grade group since several of the proportion scores correlated with grade. To provide a larger picture of the network relationships in all of the experiments presented, the correlations from Experiment 2 were compared to those found in Experiment 1A and 1B (See Table 3). In Experiment 1A, no correlations were found within the original version of the ANT with the adult sample. Within the original child version, one correlation appeared, between the orienting network and executive control network that remained significant after grade was partialled out. Perhaps this correlation indicates that participants who had the ability to utilize the orienting cues efficiently also had superior executive control networks. Also in experiment 1A, there were two correlations between the original version and the bimodal version without instructions, which were original executive control and bimodal executive control, and original orienting network and bimodal orienting network. The first correlation between executive control networks was predicted due to the fact that the flanker variable was not manipulated between the versions. This correlation was also found to be significant in the child version in the network difference scores before and after partialling out grade and in the network proportion scores before and after partialling out grade. The correlation between the orienting networks in the adults was also found in the proportion scores for the children before grade was partialled out but not after, and not at all in the difference scores. This correlation was unexpected in the first experiment because the results indicated that the adults were not utilizing the spatial cues correctly in the bimodal version but was interpreted then as indicative that some participants were using the auditory warning cues for their benefit and these individuals also had superior utilization of the visual warning cues. Finally in experiment 1A, there were two significant correlations within the bimodal without instructions version and those were executive control with alerting and orienting with alerting. Both of these correlations were later attributed to the fact that the orienting scores were simply being used as a form of alerting and that participants who were better at alerting were also better at orienting. The correlation of executive control and alerting within the bimodal version was also significant in the children's difference scores before and after partialling out grade, but not in the proportion scores. The correlation of orienting with alerting in Experiment 1A was not replicated in the child version with any scoring method. In Experiment 1B, only one significant correlation was found, and it was between the bimodal version with instruction executive control score and the orienting score from the same version. This correlation also was not replicated in any of the child version score correlations.

Table 13. Pearson's *r* Correlations from the Network Difference Scores of Experiment 2

			Original			Bimodal		
		Grade	Exec Con	Orient	Alert	Exec Con	Orient	Alert
Original	Exec Con	-0.08	--	-0.22*	0.07	0.23*	-0.18	-0.07
	Orient	0.01	-0.22*	--	0.16	0.45**	0.16	0.12
	Alert	-0.48**	0.10	0.13	--	-0.02	0.02	0.11
Bimodal	Exec Con	-0.18	*0.24	-0.44**	0.07	--	-0.12	0.23*
	Orient	0.12	-0.19	0.16	-0.04	-0.14	--	0.15
	Alert	-0.37**	-0.03	0.10	0.26*	0.28**	0.10	--

Note: Scores on the top of the diagonal represent the partial correlations after controlling for grade
* Significant at $p < 0.05$ level
** Significant at $p < 0.01$ level

Table 14. Pearson's *r* Correlations from the Network Proportion Scores of Experiment 2

			Original			Bimodal		
		Grade	Exec Con	Orient	Alert	Exec Con	Orient	Alert
Original	Exec Con	0.26*	--	-0.22*	-0.07	0.36**	-0.11	-0.20
	Orient	0.28**	-0.13	--	0.15	-0.39**	0.18	0.16
	Alert	-0.22*	-0.12	-0.14	--	-0.10	-0.02	0.08
Bimodal	Exec Con	0.21*	0.39**	-0.31**	-0.12	--	-0.03	0.07
	Orient	0.25*	-0.04	0.24*	-0.07	0.03	--	0.14
	Alert	-0.18	-0.23*	0.10	0.11	0.23*	0.09	--

Note: Scores on the top of the diagonal represent the partial correlations after controlling for grade.
* This indicates significance at $p < 0.05$ level.
** This indicates significance at $p < 0.01$ level.

Table 15. Significant Pearson's *r* Correlations within Grade Groups for Proportion Scores of Experiment 2

By Grade		*r*	*p*
Kindergarten			
None			
Second Grade			
Original Executive Control	Original Orienting	-0.56	0.01
Fourth Grade			
Bimodal Executive Control	Original Orienting	-0.52	0.01
Original Orienting	Original Alerting	0.51	0.01
Adult			
Original Executive Control	Bimodal Executive Control	0.53	0.01
Original Executive Control	Original Orienting	-0.39	0.03
Bimodal Executive Control	Original Orienting	-0.43	0.02
Original Executive Control	Original Alerting	-0.37	0.04
Original Executive Control	Bimodal Alerting	-0.46	0.01
Bimodal Executive Control	Original Alerting	-0.43	0.02

Some of the correlations between the versions in this experiment were expected due to the similarity of the task and the fact that the flanker network was not ever manipulated. The executive control scores were correlated significantly with both methods of determining network scores. The orienting scores of both versions correlate significantly in the proportion scores before grade is partialled out, but not after. Alerting scores correlated significantly between versions for the difference scores but that correlation was lost after grade was partialled out. There were 5 total correlations that disappeared after grade was partialled out, 1 in the differences scores and 4 in the proportion scores and grade, itself correlated with both alerting networks in the difference scores and all of the networks in the proportion scores except bimodal alerting. It is understandable that grade played a larger part in the proportion scores since these were created to be more sensitive to the variability of each group. Some other significant correlations not specifically discussed existed and there were several new correlations within each grade that were simply not easily explainable by previous predictions or trends in the other data analyses. According to Fan et al. (2002), theoretically, correlations within the original version should not occur because of the independence of the networks, which was supported by the results of their study and Rueda et al. (2004), but it was predicted that correlations wound be found sporadically due to the possible behavioral connections of the networks that were not present physically. Therefore, it seemed most practical to underestimate the consequences of these correlations.

Tone Practice

While the tone practice program originally served as a criterion to go on to the bimodal version of the ANT and as practice for the participants with the tones being utilized, it became evident that it was too difficult for the younger groups. The mean of all attempts at tone practice for the kindergarteners was 66.25% correct (*SD* = 17.01) and the mean of the best individual attempts was 72% correct, showing the improvement over time. The mean of all attempts for the second graders was 83.77% correct (*SD* = 11.31) and mean of best individual attempts 88% correct. For the fourth graders, the mean of all attempts was 87.97% correct (*SD* = 6.71) and the mean of the best individual attempt was 92% correct. For the adults, the mean of all attempts was 95.56% correct (*SD* = 4.07) and the mean of the best individual attempts was 97% correct. There is a steady improvement with age but it was quite dramatic in the kindergarten group. For this group the range of scores fell between 29% and 88%.

Discussion

There were several main findings of this experiment. In terms of RT, performance of the warning conditions was different for the grades. The kindergarteners and second graders did not differentiate between the spatial, center/middle, and double/chord cues, which indicated that they were not utilizing the spatial cues well in either version of the task. The fourth graders did differentiate between the center/middle and spatial cues but the double/chord cues seemed to serve a dual purpose of obviously alerting but with an additional perk in speed. Finally, the adults replicated RT findings from the original version in Experiment 1A and the bimodal version in Experiment 1B with the spatial cue significantly faster than both double/chord and center/middle cues, showing that they were able to efficiently utilize the spatial warning over the basic alerting types of warning cues.

The results of the accuracy data provided a more complex picture that did not always match the results from the RT analyses as expected. The analysis of type of error made by each grade was performed and indicated that more than half of the errors made by the children were due to not enough time allowed between the presentation of the stimuli and 1700 ms elapsed for the children to respond at all. This fact called into question the reliability of measuring accuracy in the way prescribed and expecting it to mirror the RT results. To address this issue, the method of Mezzacappa (2004) was borrowed which prescribed analyzing the accuracy data by dividing it into two categories: commission errors and omission errors. For both types of errors, the kindergarteners made the most errors followed by the second graders but the fourth graders and adults did not differ in amount of errors regardless of the version or error type. The warning variable played a much smaller role in the differences in the commission errors as seen in the number of interactions with warning and a slightly larger one in the omission errors but did not mirror the RT analyses in that aspect. There were many more significant interactions in the omission accuracy data but most reflect the fact that the relationship between center/middle and double/chord are not always consistent and also the relationship between neutral and congruent flanker conditions. These relationships are not as vital to the larger purpose of the ANT task because these are the control conditions by which the others are measured. In the future, additional analyses focusing in on the most appropriate control condition could put more meaning into these varied relationships.

The network scores provided a basis for many conclusions. When the difference scores were used, the only apparent age change was in the alerting network but when the proportion scores were used, both the orienting and executive control scores changed with age. However, three of those age-related differences involved a significant difference between the adults and the second grade. This was an indication that either an abnormal sample of second graders was obtained or that perhaps an interesting shift in cognition occurs in this age group that could be limiting their use of the spatial cues in either the original version or the bimodal version. The finding of only one significant age difference, which was in the alerting score, replicated Rueda et al. (2004). On the other hand, Rueda et al. (2004) reported finding no significant correlations between the networks using the network difference scores. One significant correlation appeared in our results within the original child version, which was between the executive control network and the orienting network.

Overall, it was difficult to find strong support for any of the proposed hypotheses because of the questions that arose from the results of the original child version. Those questions focused on the appropriateness of the time limit for children, the differences found in right versus left facing targets, the differences in the "control" conditions, and the correlation found within the original version when the networks were said to be independent. It was apparent that RT increased and error rates decreased with increasing age in both versions of the task. It seemed that children were less efficient processors of spatial cues in both the bimodal and the original version. The underlying cause for this was most likely the inability to perform the basic components of the task as easily as the adults did, which was seen in the amount and type of errors made by the children.

Of all of the hypotheses, it appeared that the "Overall Slowing Hypothesis" was the best fit for the child version data for two reasons. The RTs for all grades were higher in the bimodal version. The network scores for both versions showed a mostly linear trend except that the scores from the bimodal version were generally equal to or lower than the scores of the original version. The largest weakness to that hypothesis lied in the somewhat strange results of the second graders. The extraordinarily low bimodal orienting scores for the second grade created the illusion that the kindergarteners performed better than the second graders in the use of the auditory spatial cues, which would lend credence to the "Beneficial Effect Hypothesis." This, however, was doubtful because the kindergarteners also had superior original orienting scores than their own bimodal orienting scores. That observation combined with the poorer original version orienting scores for the second graders than Rueda et al. (2004) reported gave support once again to the "Overall Slowing Hypothesis." That hypothesis also predicted an equal detriment to performance in all networks within each grade group and the proportion scores showed just that result. The final hypothesis, "Detrimental Effect Hypothesis," was more easily discounted because of a general lack of age differences in the RT analysis. Only the second graders showed consistent age differences from the adults, whereas, the kindergarteners should have also showed extreme age differences in the network scores to support this hypothesis.

GENERAL DISCUSSION

There were several important findings from this study but one overarching theme. The one finding that consistently appeared was that performance on the bimodal version of the ANT increased response times, increased errors, and otherwise decreased efficiency as compared to performance of the original version of the ANT. In Experiment 1A, the adults performed worse on the bimodal ANT in terms of accuracy and response times but also did not reveal any benefit from the spatial cues. In Experiment 1B, it was discovered that adults could utilize the spatial cues effectively but performance was still poorer overall than the performance of adults on the original version in Experiment 1A. In Experiment 2, the children were told the purpose and utility of the spatial cues to determine if they too could utilize them as effectively as the adults when compared to performance in the original version. In many ways, the youngest children did not show evidence of using the spatial cues effectively in either version, but especially the bimodal version of the ANT.

Three hypotheses were being tested by this study, which will be discussed from most supported to least supported by the evidence. The one that received the most support was the Overall Slowing Hypothesis. This hypothesis predicted that since attention is unitary and limited by capacity, performance in the bimodal version required a translation step to process an auditory stimulus into a visual expectation for the target, therefore, decreasing performance across all measures of the task (Kail, 1991; Cowan, 1999; Engle, Kane, & Tuholski, 1999). The finding of slower and less accurate performance in the bimodal version found in all three experiments was the most compelling source of support for this hypothesis. In addition, the network scores between the original version and the bimodal version parallel one another showing that similar, if not the same, mechanisms were at work. In the child version, both the kindergarteners and second graders did not differentiate between the center/middle, double/chord, and spatial conditions, which indicated that these two groups were not performing efficiently in the orienting conditions. Their orienting scores were lower in the bimodal version than the original version. This more complex aspect of the task, as seen in Experiment 1A where adults did not use spatial cues efficiently in the bimodal version, is the first to suffer when task demands exceed the attentional capacity.

The Beneficial Effect Hypothesis was built around the proposition that attention could represent two separate mechanisms that perform the same processes but deal specifically from stimuli received from either the visual modality or the aural modality (Sloutsky & Napolitano, 2003; Robinson & Sloutsky, 2004; Bedi, Halperin, & Sharma, 1994; and Benedict et al., 1998). This hypothesis also predicted an auditory processing dominance in the youngest children with a switch to a visual processing dominance in older children and adults. The strongest evidence for this hypothesis came from Experiment 2 in the orienting scores of the kindergarteners which appeared to be superior to the second grade group, but as discussed before, it most likely the result of irregular data from that sample of second graders.

However, the lack of correlational evidence from Experiment 1A and 1B suggested that different attentional mechanisms were involved. The conditions that went into the executive control network were not manipulated but the executive network scores between the original ANT in 1A and the bimodal ANT from 1B did not correlate. This correlation was present within Experiment 1A when adults were not utilizing spatial cues in the bimodal version, which shed some doubt on the meaning of that correlation because the adults were not performing the task correctly. However, this correlation of executive control scores was found in the child ANT data. This could once again suggest that, overall, the task was not being performed correctly or that the correlation is so sensitive that it could only be found when the tasks are compared within-subjects. However, the exact nature of most of the correlations is still unknown. Jin Fan and Michael Posner, the creators of the ANT, have suggested that all of the networks could be behaviorally linked or even overlap in processing without predicting what each correlation would actually indicate (Fan et al., 2002; Fan & Posner, 2004).

No significant evidence was found in support of the Detrimental Effect Hypothesis. This hypothesis predicted that the unitary mechanism of attention possessed severely limited capacity in early development with a priority for visual stimulus over an auditory stimulus such that in the presence of an auditory distractor, performance with the visual modality suffers (Elliott, 2002; Hanauer & Brooks, 2003).

Another result that should be noted was the difference between the bimodal and original versions in terms of the utilization of spatial cues. In Experiment 1A and 1B, it was suggested that the visual warning cue created automatic orientation to the future location of the target but that the auditory spatial cue required a conscious level of processing. However, after reviewing the results of the Experiment 2, it would seem that the processing of the visual spatial cue was not automatic for the younger children. This inconsistency would indicate that the response to the spatial cues could not be an inherently automatic process at all, supporting the theory of Pashler (1998) regarding automaticity.

Limitations

There were several limiting factors to the ability to generalize the results previously discussed. The correlations between networks within a version were not consistent across each of the experiments and often lacked an obvious cause for such a correlation to exist. These correlations even varied within the same sample in Experiment 2 when the method of calculating the network scores was altered to take into account age variability in RT. The performance of the children also called into question the validity of using the ANT with those age groups. Not only were the error rates very high, but the errors also consisted of a substantial number of "time out" errors. These errors decreased the ability of the RT measure and accuracy measure to show similar patterns. The pattern of results in the double/chord conditions suggested that, in the children, this warning was not simply an alerting cue but improved performance more than a center/middle cue.

The performance of the second grade group in Experiment 2 was the most disconcerting aspect of the study. While the RT and accuracy scores indicated that the second graders were predictable in their relationship to the kindergarteners and fourth graders, the orienting network scores were very low for both versions of the tasks. Perhaps the most logical explanation of this occurrence was a poor sample from the population. Another possible explanation could lie in the ability to utilize strategies at this age. While unlikely, the possibility existed that these children were attempting to utilize a strategy but, due to limited capacity, poorer performance than if they had not used a strategy was elicited (DeMarie-Deblow & Miller, 1988). An interesting detail about the method during Experiment 2 was that all children were informed of the purpose and use of the warning cues for both versions of the task due to the findings in Experiment 1A. Adults did not utilize the auditory spatial warning cues when they were not told about them so to ensure that the children would also attempt to utilize the cues, we added to the original instructions for the child version. In previous experiments, children were simply given the instructions of how to perform the task in certain flanker conditions without even a brief mention of the existence of the warning conditions (Reuda et al., 2004; Mezzacappa, 2004). Perhaps this difference in instructions had an unforeseeable effect on the performance.

Future Directions

The ANT holds many possibilities for future experiments. Both variables' modalities could be switched so that the flanker variable could be presented aurally and the warning variable visually as to test the opposite bimodal version. The validity of the warning cues could be manipulated to assess the decision to utilize cues if they are not always accurate or the point at which the cues become a distraction rather than a benefit to performance. The ANT, as suggested by Fan and Posner (2004), can be utilized to determine deficits such as ADHD or schizophrenia, and I suggest that the bimodal version could also be utilized with adults because of the observations that persons with ADHD or often very audibly distractible and the schizophrenic delusions are auditory in nature. The differences in attentional mechanisms that may not be evident in normal populations could appear in special populations because of different neural organizations.

Conclusions

The bimodal ANT in comparison with the original ANT provided a method of analyzing the mechanism(s) of attention by providing similar information in two different modalities (audition and vision) while maintaining the modality and organization of the other variable. Findings suggested that the attentional mechanism is unitary in nature but limited in capacity. The capacity increased linearly with age allowing the participant to respond more quickly and accurately while utilizing beneficial cues more efficiently as he reaches adulthood. Results from the original ANT task generally replicated those previously reported by Fan et al. (2002) and Rueda et al. (2004) but several inconsistencies called into question the validity of the task and the efficacy of using this task with children ages 6-10 years.

In going back to the original question of whether attention is a unitary or divided mechanism, our study supports a mechanism that is not divided by modality. However, in terms of the Attentional Networks, we did find that there were three mostly distinct networks, executive control, orienting, and alerting, as described by Fan et al. (2002). In addition, this study showed that these networks were all taxed when stimuli were presented in separate modalities as compared to the single modality original version. This taxation is seen even more clearly in the younger age groups. The orienting network often suffered the greatest in RT performance suggesting that this mechanism is the least automatic and most likely to be neglected when processing of varied modalities of information from the outside world. In those terms, the three networks are sharing common resources, which limits that autonomy and the appearance of independence in development. This suggests that the attentional system begins in early life stages as an unspecialized area and through physical development and experience, the networks emerge as separate entities. Thus, the study of how people deal with information from multiple sensory modalities can inform us of the development of the mechanisms in charge of regulating attentional resources.

REFERENCES

Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4,* 417-423.

Baddeley, A. D., & Hitch, G. J. (1974). Working Memory. In G. A. Bower (Ed.), *The Psychology of Learning and Motivation* (pp. 47-89). Academic Press.

Bedi, G. C., Halperin, J. M., & Sharma, V. (1994). Investigation of modality-specific distractibility in children. *Internal Journal of Neuroscience, 74*, 79-85.

Benedict, R. H. B., Lockwood, A. H., Shucard, J. L., Shucard, D. W., Wack, D., & Murphy, B. W. (1998). Functional neuroimaging of attention in the auditory modality. *NeuroReport, 9*, 121-126.

Callejas, A., Lupianez, J., & Tudela, P. (2004). The three attentional network: On their independence and interactions. *Brain and Cognition, 54,* 225-27.

Cowan, N. (1999). An embedded-processes model of working memory. In A. Miyake, & P. Shah (Eds.), *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control* (pp. 62-101). New York: Cambridge University Press.

Cowan, N., & Barron, A. (1987). Cross-modal, auditory-visual Stroop interference and possible implications for speech memory. *Perception and Psychophysics, 41*, 393-401.

DeMarie-Dreblow, D., & Miller, P. H. (1988). The development of children's strategies for selective attention: Evidence for a transitional period. *Child Development, 59,* 1504-1513.

Elliott, E. M. (2002). The irrelevant speech effect and children: Theoretical implications of developmental change. *Memory and Cognition, 30* (3), 478-487.

Elliott, E. M., Cowan, N., & Valle-Inclan, F. (1998). The nature of cross-modal color word interference effects. *Perception and Psychophysics, 60* (5), 761-767.

Elliott, E. M., McDonald, J. L., Lynn, S. D. & Alonzo, J. L. (2006). *Developmental change in the time course of interference in the cross-modal Stroop effect.* Manuscript in progress.

Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In A. Miyake, & P. Shah (Eds.), *Models of Working Memory: Mechanisms of Active Maintenance and Executive Control* (pp. 102-134). New York: Cambridge University Press.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception and Psychophysics, 16* (1), 143-149.

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*(3), 340-347.

Fan, J., McCandliss, B. D., Flombaum, J. I., & Posner, M. I. (2003). Cognitive and brain consequences of conflict. *Neuroimage, 18*, 42-57.

Fan, J., & Posner, M. (2004). Human attentional networks. *Psychiat Prax, 31* (2), S210-S214.

Fossella, J., Sommer, T., Fan, J., Wu, Y., Swanson, J. M., Pfaff, D. W., & Posner, M. I. (2002). Assessing the molecular genetics of attention networks. *BioMed Central Neuroscience, 3*, 14.

Gomes, H., Molholm, S., Christodoulou, C., Ritter, W., & Cowan, N. (2000). The development of auditory attention in children. *Frontiers in Bioscience, 5*, d108-120.

Guttentag, R. E. (1985). A developmental study of attention to auditory and visual signals, *Journal of Experimental Child Psychology, 39*, 546-561.

Hanauer, J. B., & Brooks, P. J. (2003). Developmental change in the cross-modal Stroop effect. *Perception and Psychophysics, 65*(3), 359-366.

Kail, R. (1986). Sources of age differences in speed of processing. *Child Development, 57*, 969-987.

Kail, R. (1991). Developmental change in speed of processing during childhood and adolescence. *Psychological Bulletin, 109* (3), 490-501.

Kail, R. & Salthouse, T. A. (1994). Processing speed as a mental capacity. *Acta Psychologica, 86*, 199-225.

Mezzacappa, E. (2004). Alerting, orienting, and executive attention: Developmental properties and sociedemographic correlates in an epidemiological sample of young, urban children. *Child Development, 75* (5), 1373-1386.

Pashler, H. E. (1998). *The Psychology of Attention.* Cambridge: The MIT Press.

Rakauskas, M. E., & Ward, N. J. (2005). Behavioral effects of driver distraction and alcohol impairment. Presented at the 49th annual meeting of the Human Factors and Ergonomics Society, Orlando, Florida, September 26-30, 2005.

Robinson, C. W., & Sloutsky, V. M. (2004). Auditory dominance and its change in the course of development. *Child Development, 75*(5), 1387-1401.

Rueda, M. R., Fan, J. McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., & Posner, M. I. (2004). Development of attentional networks in childhood. *Neuropsychologia, 42*(8). 1029-1040.

Salthouse, T. A., & Kail, R. (1983). Memory development throughout the life span: The role of processing rate. In P. B. Baltes & O. G. Brim (Eds.), *Life-span Development and Behavior* (Vol. 5, pp. 89-116). San Diego, CA: Academic Press.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime user's guide.* Pittsburgh, PA: Psychological Software Tools.

Sloutsky, V. M., & Napolitano, A. C. (2003). Is a picture worth a thousand words? Preference for auditory modality in young children. *Child Development, 74* (3), 822-833.

Spence, C., & Driver, J. (1996). Audiovisual links in endogenous covert spatial attention. *Journal of Experimental Psychology: Human Perception and Performance, 22*, 1005-1030.

Turatto, M., Benso, F., Galfano, G., & Umilta, C. (2002). Nonspatial attentional shifts between audition and vision. *Journal of Experimental Psychology: Human Perception and Performance, 28*, 628-639.

Ward, L. M. (1994). Supramodal and modality-specific mechanisms for stimulus-driven shifts of auditory and visual attention. *Canadian Journal of Experimental Psychology, 48*, 242-259.

Ward, L. M., McDonald, J. J., & Lin, D. (2000). On asymmetries in cross-modal spatial attention orienting. *Perception and Psychophysics, 62*, 1258-1264.

APPENDIX: ANT INSTRUCTIONS

Instructions for Performing the ANT, Given to Adults in Experiment 1B

This is an experiment investigating attention. You will be shown an arrow on the screen pointing either to the left or to the right. On some trials, the arrow will be flanked by two arrows to the left and two arrows to the right, as you can see in the examples on the instruction screen. Your task is to respond to the direction of the CENTRAL arrow. The first set has 5 arrows pointing to the right so you should look at the 3rd arrow over (the one in the middle) and respond to it. In the second example, 4 of the arrows point to the right but the middle arrow points to the left so you should respond to the center, left-pointing arrow.

You should press the left mouse button with your left thumb if the central arrow points to the left or press the right mouse button with your right thumb if the central arrow points to the right. You may hold the mouse in your hands or place your hands over it with the mouse directly in front of you but YOU MUST use your thumbs on each of the buttons to indicate the direction of the target arrows.

Please make your response as quickly and accurately as possible. Your reaction time and accuracy will be recorded. There will be a cross ("+") in the center of the screen and the arrows will appear either above or below the cross. You should try to fixate on the cross throughout the experiment. Try to maintain fixation at all times.

On some trials there will be a tone before the arrow appears. The tones are identical to the tones you heard during the program you just finished. If the tone is middle frequency or a chord, it indicates that the arrow will appear shortly. If the tone has a high or low frequency, it also indicates that the arrows are about to appear but in addition they tell you <u>where</u> the arrow will soon appear. In other words, a high tone indicates that the arrow will appear above the fixation cross and a low tone indicates that the arrow will appear below the fixation cross. Since the tones are present to assist you, please pay close attention to them so that your responses can be quicker.

The experiment contains four blocks. The first block is for practice and takes about two minutes. The other three blocks are experimental blocks and each takes about five minutes. After each block there will be a message "take a break" and you may take a short rest. After it, you can press the space bar to begin the next block. The whole experiment takes about twenty minutes.

Do you have any questions? (If yes, clarify the instructions) If No go on to say- Then you may press SPACE bar to start the practice session.

VITA

Sharon Diane Lynn was born on February 17, 1982, in Euless, Texas, to her parents Charles R. Brown and Shirley A. Brown. She grew up in Texas with her family and attended public schools in Saginaw, Texas, throughout her primary and secondary education. After graduating high school in May 2000 with several honors and ranked 10^{th} in her class, Sharon attended Harding University in Searcy, Arkansas. After a year at Harding, she came home to Saginaw and married her high school sweetheart, Lashan Densmore-Lynn. She then attended Tarrant County College for a year and gave birth to Jade K. Lynn, her daughter, in February 2002. She transferred the following school year to the University of Texas at Arlington, where Sharon completed her Bachelor of Arts degree in psychology in May 2004, at the top of her graduating class. She then moved to Louisiana to pursue her graduate training in cognitive developmental psychology at Louisiana State University in June 2004. She was divorced in April 2006, and completed the requirements to earn her Master of Arts degree in psychology in May 2006. Sharon plans to complete her doctoral studies at Louisiana State University in 2009 and go on to a career in academia and to pursue her research of how memory and attention develops through middle childhood.