

Running head: A NEW ATTENTION TASK

Validation and Characterization of a New Attention
Task in Typically Developing Children and Adolescents

by

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Table of Contents

Abstract.....	5
Introduction.....	6
Attention Networks.....	6
Development of the Brain.....	8
Research on Attention: The ANT.....	10
The ANT and Children.....	11
Limitations of the ANT.....	15
Methods.....	19
Participants.....	19
Characterization Measures.....	19
Conners Rating Scale-Revised.....	20
Social Responsiveness Scale.....	20
Wechsler Abbreviated Scale of Intelligence.....	21
Combined Attention Systems Task.....	21
Design and Analyses.....	23
Data Pre-Processing.....	24
Results and Interpretation.....	26
Demographic Characteristics.....	26
Analyses of Main Effects.....	26
Analyses of Interactions.....	27
Non-significant relationships: RT.....	28
Non-significant relationships: Error rate.....	28
Discussion.....	29
Main Effects.....	29

Interactions between main effects and characterization measures.....	30
Alerting.....	30
Spatial Orienting.....	31
Executive Function.....	32
Validity of the CAST for Child and Adolescent Participants.....	32
Excluded Participants.....	33
Application to ADHD and School Psychology.....	33
Limitations and Future Directions.....	35
Conclusion.....	37
References.....	38
Tables.....	40
Figures.....	41

Abstract

Research has shown that our attentional system is comprised of three different networks: alerting, orienting, and executive control. While much research has been completed on these attentional networks, studies have most often employed the Attention Network Task (ANT). Even though the ANT is widely used in attentional research and has been revised, modified and/or adapted to be child-friendly, the fact remains that it has several psychometric and methodological limitations. The purpose of the present study was to examine the validity of the Combined Attentional Systems Task (CAST), a new attentional task developed in response to the limitations of the ANT. A total of twenty-four typically developing children and adolescents (ages 8-16) completed the CAST. Overall, results yielded the expected main effects for orienting, alerting and executive control. Age effects were also found for participant reaction times for orienting and executive control. These findings provide support for the validity of the CAST in the age range examined in the current study.

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Attention Networks

Previous research has provided solid evidence for the idea that our attention system is comprised of three independent networks which are known as the executive control network, the orienting network, and the alerting network (Callejas, Lupianez, Funes, & Tudela, 2005). The executive control network, thought to be supported by the anterior areas of the frontal cortex, is known to control processes, such as conflict resolution and detection of errors (Callejas et al., 2005). It is thought to be active when our cognitive system plans, makes a decision, detects an error, gives a novel response, or overcomes a habitual action. In order to assess attentional executive control, the tasks that are used often involve conflict resolution, novelty, and/or error detection. Two types of tasks are commonly used: stroop tasks and flanker tasks. Stroop tasks involve cognitive conflict, which takes the form of overcoming a habitual action or response (e.g., overcoming habitually providing a response that matches the side of the screen where the stimuli is presented). Flanker tasks involve a central stimulus (e.g., an arrow), surrounded or flanked by other stimuli (e.g., arrows) that can either be congruent (e.g., flanker arrows pointing in the same direction as the central arrow) or incongruent (e.g., flanker arrows pointing in the opposite direction as the central arrow). The incongruent trials present a conflict resolution situation and require inhibition because one must ignore the flanker information and respond to the target.

The orienting network, thought to be supported by the posterior parietal lobe, the superior colliculus and the pulvinar nucleus of the thalamus, directs our processing system to the source of the input by allocating our attention to a potentially relevant area of our visual field, thus

enhancing our processing (Callejas et al., 2005). Finally, the alerting network, thought to be supported by many more diffuse locations within the brain, prepares our attention system for fast responses by keeping a constant level of activation within our cognitive system (Callejas et al., 2005). Based on the tasks used to measure the alerting network, two types of alertness have been described: vigilant or phasic. Vigilant alertness is thought to be a more sustained level of activation which is relatively constant over a period of time, and phasic alertness is thought to be intermittent, occurring when a warning signal is presented before a target to increase alertness. While these three networks are each associated with different areas of the brain and thus hypothesized to be independent, some research has examined the interactions between the networks.

Funes and Lupianez (2003 (in Spanish), as cited in Callejas et al., 2005) examined the influence of the orienting network on the executive control network. In this study, participants were required to discriminate the direction of an arrow, while the task combined a spatial stroop task with visual orienting cues and auditory alerting cues. In this way, the location and direction of the arrow could be either congruent (e.g., the arrow pointing leftwards located on the left-hand side of the screen) or incongruent (e.g., the arrow pointing leftwards located on the right-hand side of the screen). Also, a spatial cue could appear either at the location of the target (cued trials) or at the opposite location (uncued trials), with equal numbers of cued and uncued trials. An auditory alerting sound was used on half of the trials. Results indicated a reduction in spatial stroop effect when the conflicting stimulus appeared at the correctly cued location (e.g., spatial stroop characterized by a left pointing arrow on the right hand side of the screen, but correctly cued to appear on the right hand side of the screen). In addition, the spatial stroop effect was larger under conditions of high alertness. It was also smaller for cued trials than for uncued trials.

Thus, although the attention networks are often conceptualized as being independent, this set of results indicates important interactions between them that must be considered in future research.

Development of the Brain

In light of our interest in examining attention networks in children and adolescents, it is important to consider what we know about the course and timing of brain development. Giedd (2008) explains that while it is not surprising to hear that the brain of a 16-year-old is different than the brain of an 8-year-old, pinpointing the differences in a scientific way has been difficult. In addition, the onset of puberty can vary in individuals by as much as six years, making adolescence difficult to define biologically (Giedd, 2008). Giedd describes how the use of MRI scans, which combine radio waves, strong magnetic fields, and computer technology provide researchers with information on the anatomy and physiology of the brain, allowing more insight into brain development.

Giedd (2008) used data collected by a National Institute of Mental Health (NIMH) Child Psychiatry Branch (CPB) Longitudinal Brain Imaging Project which began in 1989, and by 2007 consisted of approximately 5000 scans from 2000 participants. Of the original participants, only 387 participants (ages 3-27 years) remained free from psychopathology. The 829 scans from these participants were used in this review. Within this cohort, total cerebral volume was found to peak at age 10.5 for females and 14.5 in males, and by age six the brain had reached approximately 95% of this peak with the mean total cerebral volume being 10% larger in males (Giedd, 2008). The cerebellum volume was found to peak approximately two years later than cerebral volume, with the lateral ventricular volume increasing robustly with age in the healthy sample. Not surprisingly, white matter volume increased throughout childhood and adolescents within the sample, sometimes found to increase by as much as 50% within a 2 year period in

some areas (Giedd, 2008). In contrast, gray matter followed an inverted U-shape pattern of growth, reaching a peak and then falling. Gray matter volumes were found to peak at age 9.5 for females and 10.5 for males in the frontal lobes, at ages 10.0 in females and 11.0 in males in the temporal lobes, and at ages 7.5 in females and 9.0 in males in the parietal lobes (Giedd, 2008).

The basal ganglia are made up of a collection of subcortical nuclei (caudate, putamen, globus pallidus, subthalamic nucleus, and substantia nigra) that are involved in circuits that mediate movement, higher cognitive functions, attention, and affective states (Giedd, 2008). Much like gray matter, the growth pattern for this area of the brain followed an inverted U-shape trajectory, which peaked at age 10.5 in females and 14.0 in males. Much like there is no specific onset of adolescence, all of these above mentioned findings support the idea that there is no specific onset of brain maturation and that there are differences in maturation times between males and females and for distinct brain regions.

It is important to consider the course of brain development when examining cognitive abilities, including attentional networks, and to bear in mind how brain development might be related to these abilities. Given that many brain regions are involved in attention, it is important to think about the broader view when considering Giedd's (2008) findings. For example, basal ganglia and frontal lobes are areas that are likely important in the executive attention network and findings suggest peak ages of development of both areas around age 10 for girls, with some later maturation for boys, especially for basal ganglia. Thus, both age and sex may be important variable to consider in analyses of attentional networks and this may be more important for executive attention relative to alerting and orienting.

Research on Attention: The ANT

A task that is commonly used to measure attention is the Attention Network Task (ANT) developed by Jin Fan in 2002. The ANT was specifically developed to independently measure the efficiency of the three attention networks (alerting, orienting, and executive function) by using a short and simple computer task. This task is popular in neuropsychological literature, appearing in approximately sixty-five original research papers since 2001 (MacLeod et al., 2010). During the ANT, participants are asked to indicate the direction that an arrow is pointing on the computer screen. Please see Figure 1 for a flow chart of the ANT. The stimulus consists of a central arrow that is flanked by either four arrows, which can be pointing in the same direction as the target arrow (congruent) or pointing in the opposite direction (incongruent), or is flanked by straight lines/has no flankers which would be the neutral condition (MacLeod et al., 2010). The onset of the stimulus typically varies between 100ms and 500ms, and is known as stimulus onset asynchrony (SOA). On some trials, temporal cues are presented prior to the onset of the stimulus (arrows) to indicate that the stimulus will appear soon. The temporal cues consist of either a central single cue (asterisk) located at fixation, a double cue consisting of two asterisks, one located above fixation and one located below fixation (which indicates the arrow will occur soon), or a temporal and spatially informative single cue (either above or below fixation) which is 100% predictive of the target arrow's location. Participants' performance is measured as both reaction times (RT) and error rates (ER).

According to MacLeod et al. (2010), RT efficiency for each attention network can be calculated using subtractions for RT data for accurate trials. For example, MacLeod et al. (2010) reported that to calculate the alerting network score, RT in the temporally informative double cue condition is subtracted from RT in the temporally uninformative no cue condition. For the

orienting network score, RT in the spatially informative cue condition is subtracted from RT in the spatially uninformative central cue condition (averaging across all flanker conditions). Finally, the executive control network score is calculated by subtracting RT in the congruent flanker condition from RT in the incongruent flanker condition (averaging across all cue conditions).

In 2007, Jennings, Dagenbach, Engle and Funke examined the effects of age in adults on the alerting, orienting, and executive control function using the ANT. Participants were divided into two age groups, the first group totalling 123 individuals with an average age of 69.1 years (range 61-87) and the second group totalling 60 individuals with an average age of 19.2 years (range 18-21). Participants completed two sets of 96 trials of the ANT, and their data was analysed using the above mentioned subtraction method to obtain network scores. Results showed a main effect of age, with older adults responding slower than young adults across all cue and flanker conditions but no interactions among network scores.

The ANT and Children

There is also growing interest in attention networks in children and this will be the primary focus of this thesis. Rueda et al. (2004) suggested that alerting and executive functioning develop throughout childhood, while orienting may be stable after infancy. It is important to understand typical development of attention so that studies examining children with atypical attention (e.g., children with Attention Deficit-Hyperactivity Disorder) can determine if and how attentional networks differ from the expected trajectory.

Rueda and colleagues (2004) adapted the Attention Network Test (ANT), which is used to measure the efficiency of the three networks with adults, to study the development of these networks during childhood. The adapted test is merely a child-friendly version of the ANT

flanker task with alerting and orienting cues. The arrows are replaced by one central fish or five horizontal fish (one central fish and four flanker fish), and children are asked to help feed the fish by pressing a button that corresponds to the direction that the middle fish is swimming (Rueda et al., 2004). Rueda et al. (2004) used the children's version of the ANT with children ages six through nine to examine the development of these three attention networks.

Participants were grouped by age (four groups: age six, age seven, age eight, and age nine) and each group consisted of twelve participants. Results for RTs showed a main effect for age, cue type, and flanker type, while results for ER showed main effects for age and flanker type. Overall, results showed that reaction times were faster and error rates were lower for older children compared to younger children. There were no differences between the age groups for the alerting network and although there was some suggestion of a smaller orienting effect for older children, these findings were not significant. Finally, seven year olds showed a smaller executive network effect than six year olds, but there were no other differences for the other age groups (Rueda et al., 2004).

In another study, Rueda et al. (2004) compared the results of adults (mean age 27 years) and children (mean age 10 years, 4 months) on the two versions of the ANT: arrow (adult version) and fish (child version). There were significant differences between adults and children in overall RT, with adults being faster than children. The adults had faster reaction times in the alerting network, but only on the adult ANT (arrows). In other words, while adults benefited from hearing a tone prior to the stimulus onset in the adult version of the ANT, in the child version of the ANT the adults did not benefit from hearing a tone. This suggests that they may have been able to maintain alertness while completing the child version of the ANT, but not

during the less animated adult version. Surprisingly, for the executive control network, adults were not significantly more efficient than children on either version of the test.

Finally, Rueda et al. (2004) completed a second study with the intention of replicating their initial findings that indicated no interactions between conditions (supporting independence of the three networks). Comparison of data from children who completed two of their previous studies indicated somewhat larger effects of alerting and orienting in the first study, but very similar scores for the executive control network. Rueda et al. (2004) noted that in both studies there were no interactions between the type of cue and type of flanker which supports independence between the networks in children.

In summary, orienting scores were consistent in participants ranging from six years to adulthood on this task, indicating that cues to help orient attention to the correct location improved RT for all ages. During childhood, the alerting network scores seem to stabilize around middle childhood, but the scores are still found to be higher in adulthood. Rueda et al. (2004) suggested that large alerting scores (i.e. larger differences) occur between cue and no cue trials for children due to the fact that it may be more difficult for children to maintain a constant alert state when there is no cue and thus they rely more on the cue to enhance their attention. Finally, Rueda et al. (2004) found lower executive control scores (i.e., better performance) in seven year olds, compared to six year olds, and then very similar scores across ages seven through adulthood, suggesting a stabilizing of this network.

In 2005, Callejas et al. developed an integrated Attention Network Task (ANT-I) in order to examine each of the three attentional networks and the interactions between them. An important difference is that the ANT-I includes alerting tones (which can be present or absent) instead of the visual central/double/spatial or no cues as in the ANT. Another difference is that

spatial cues in the ANT-I (e.g., an asterisk above or below the fixation cross) are unpredictable of target location (either above or below)

In a study by Callejas et al (2005), twenty-four female undergraduate students (aged 19-25) completed the ANT-I and results showed that trials with auditory cues (test of the alerting network) had faster reaction times (RTs) than those without auditory cues, trials with stimuli present in the same location as the cue (test of the orienting network) had faster RTs than at the opposite location, and trials with congruent or neutral flankers (test of the executive control network) had faster RTs than incongruent flankers. Significant interactions were found between visual cue and congruency (larger for uncued than cued), between auditory signal and congruency (greater congruency effect when an auditory signal was present than when it was absent).

A second experiment by Callejas et al. (2005) included forty-eight undergraduate psychology students (aged 19-24) who completed the ANT-I, with minor variations made by the researchers. The stimulus onset asynchrony (SOA) was either 100 or 500 milliseconds (with the visual cue shortened to 50 ms) and the neutral condition was removed. Results showed similar patterns to their first experiment, with significant interactions between visual cue and congruency and between auditory signal and congruency, as well as an additional significant interaction between auditory signal and visual cue (larger visual cueing effect in alerting conditions). Callejas et al. (2005) also examined the effects of SOA and found that a three way interaction between auditory signal, visual cue and SOA approached significance.

The results of these two experiments by Callejas et al. (2005) provided support for the idea that the alerting network interacts with the orienting network by speeding up the process of

orienting. The results also provide information on the way our attention system works as a whole, and how the three networks coordinate with each other to be one effective system.

A study by Mullane, Corkum, Klein, McLaughlin and Lawrence (2011) used the ANT-I to examine the alerting, orienting, and executive attention abilities of children with diagnosed with ADHD and typically developing peers. The process of diagnosing participants with ADHD was rigorous and included ratings by a trained psychologist, as well as parent and teacher questionnaires and interviews. Results showed that children with ADHD showed weaker alerting and executive attention abilities than their typically developing peers. Results also showed that children with ADHD-Combined type did not differ from children with ADHD-Inattentive type.

Limitations of the ANT

The ANT has been used to examine attentional networks in individuals with dyslexia, schizophrenia, borderline personality disorder, attention-deficit hyperactivity disorder, and gene deletion syndromes. According to MacLeod et al. (2010), many studies have used ANT results to claim that certain clinical populations demonstrate attentional deficits in a specific attentional network instead of an overall attention deficit. One important limitation of the ANT is its inability to differentiate between the alerting and orienting effects. That is, the spatial orienting cue, which occurs after the alerting tone (if provided), always occurs at the same time with regard to the onset of the stimulus. This means that the alerting tone is not necessary to prepare for the onset of the stimulus because the orienting cue always does so. MacLeod et al. (2010) also reported that alerting network scores have been used to differentiate ADHD subtypes. Given the extensive use of the ANT, one would expect that the validity and reliability of the ANT would be strong. MacLeod et al. (2010) argued that while the face validity of the ANT is good, the reliability of the network scores have been low to moderate in several studies that have

examined its reliability in normal populations. Specifically, the executive control measure is the most reliable measure, followed by the orienting network measure, and then the alerting network measure (MacLeod et al, 2010).

In 2010, MacLeod and colleagues reviewed all available published research which used the ANT to examine the either evaluate the difference in network scores between groups or between testing periods, or to examine the correlation between attention network scores and another measure, for a total of thirty-nine studies. MacLeod and colleagues (2010) found that significant executive control network effects (i.e., groups or testing periods were significantly different from each other) were observed in thirty-one studies (79%), significant orienting network effects were observed in twelve studies (30%), and significant alerting effects were observed in fifteen studies (38%). This pattern suggests that the executive effects are quite robust, but that the presence of orienting and alerting effects is more variable and thus, is suggesting that the ANT may not validly assess these networks. The test-retest reliability estimates of the ANT, which are .77 for executive control, .61 for orienting and .52 for alerting also suggest some psychometric limitations (Fan, McCandliss, Sommer, Raz and Posner, 2002).

MacLeod and colleagues (2010) further examined the psychometric properties of the ANT by compiling data from numerous studies that used the ANT with healthy participants ages 16 to 65 years (N=1,129). Examining reliability of RT yielded findings similar to previous research, such that the executive network was the most reliable, followed by the orienting network and then the alerting network. When considering ER, the executive network was the most reliable, followed by the alerting network, and then the orienting network (MacLeod et al., 2010). For RT, the within-subjects variance of executive network scores was less than that of the orienting network scores, which was less than that of the alerting network scores. For ER, the

within-subject variance of executive network scores was less than that of the orienting and alerting network scores, which were not significantly different. These findings map well onto those of previously obtained reliability results of the ANT. Overall, research to date indicates that the ANT is not a highly reliable tool for examining individual differences and network-specific effects and that this is particularly true for orienting and alerting).

In response to the limitations of the ANT reported by MacLeod et al. (2010), a new attention task was developed by Mike Lawrence: the Combined Attention Systems Task (CAST). The CAST also examines the orienting, alerting, and executive control networks of the attention system, but does so in a manner that is expected to be more reliable and valid. The CAST was developed to address the limitations of the ANT and ANT-I, particularly the inability to separate the alerting cues from the spatial orienting cues. The CAST is a simple computer task which utilizes cartoon-like fish as stimulus (rather than arrows as in the ANT). Participants are presented with an arrow facing to either the left-hand side or the right-hand side of the screen. This arrow is predictive 75% of the time, and participants are told this during instructions. The arrow is always surrounded by a shape, either a circle or a square. One of the shapes indicates that a tone will occur one second before the onset of the stimulus (fish). The opposite shape indicates that a tone will not occur prior to the onset of the stimulus. In the current study, for half of the participants the circle indicated that a tone would occur and for the other half the square indicated that a tone would occur. The duration between the arrow-shape cue and the stimulus is a random exponential interval (aka. a non-aging interval) with a minimum of 1 second and a mean of 2 seconds. This means that on tone absent trials, the timing of the stimulus onset is not predictable. The stimulus is comprised of either a single fish, or a central fish flanked by four other fish. These flankers are congruent or incongruent.

The development of a task that can be used to assess the attention networks of individual children would be an important addition to neuropsychological and psychoeducational assessment measures. The present study is the first validity study of the CAST in children and adolescents. The primary goal is to examine the validity of the CAST, by evaluating the expected main effects of the three networks. We will also examine relationships between network scores and age, IQ, and parent-reported attentional abilities and autistic features in order to begin to characterize how other participant variables relate to performance on the CAST. Although reliability of the CAST is an important consideration, this question will be addressed by a future study.

If indeed the CAST is a valid measure, it is hypothesized that main effects will be present for the four conditions: 1) Alerting: tone present trials will result in faster RT scores and lower ER scores compared to tone absent trials; 2) Spatial Orienting: valid arrow trials will result in faster RT scores and lower ER scores compared to arrow invalid trials; 3) Executive control: spatial stroop congruent trials will result in faster RT and lower ER scores compared to incongruent trials; 4) Executive control: congruent flanker trials will result in faster RT scores and lower ER scores when compared to incongruent trials. In addition, it is expected that 5) there will be an overall effect of age, such that older children will perform faster than younger children. It was also hypothesized that 6) younger children will be more affected by flankers since frontal lobe development is known to continue well into adulthood and is believed to underlie continued development of executive functions such as those involved in ignoring incongruent flankers. It was also expected that 7) participants with better attention scores and fewer autistic features would have faster RT scores and lower error rates compared to those with

higher scores. Finally, 8) participants with higher IQ scores were expected to perform faster and have fewer errors.

Method

Participants

Previously collected data from thirty-one typically developing children and adolescents, age range 8-16 (Mean=11.65), who participated in an ongoing study examining information processing in the Johnson Lab at Dalhousie University were utilized for this study. The sample of participants was comprised of eighteen males and thirteen females. Twenty-five of the participants were right-handed, while only six were left-handed. The participants were screened by means of interview with a parent, in order to ensure that all of the following exclusionary criteria were met: no history of neurological conditions, psychiatric conditions, learning disorders, and no history of any serious medical illnesses. Each participant completed approximately 2 - 2.5 hours of standardized and experimental measures. The computerized experimental measures were completed in a randomized order, and several additional measures were completed as part of a larger study that were not the focus of the current study. Thus, the CAST was administered at various time points in the testing sessions and the time points were counterbalanced for participants. One-on-one testing was completed by a graduate student or research assistant in Dr. Johnson's Lab in the Psychology Department at Dalhousie University.

Characterization Measures

In order to ensure that all participants were typically developing, several parent-report questionnaires were used to assess the possible presence of any atypical features. Specifically, questionnaires on attentional difficulties and autistic mannerisms were completed by parents of the participants. Due to the fact that Mullane et al. (2011) found significant differences between

children with ADHD and typically developing children, it was imperative that any participants with parent-reported attentional difficulties be removed from the study.

Conners Rating Scale- Revised

The parent(s) of participants were asked to complete the short version of the parent report of the *Conners Rating Scales-Revised (CRS-R; Connors, 1997)*. The CRS-R was used to assess symptoms of Attention Deficit/Hyperactivity Disorder (ADHD) and associated problem behaviours. The CRS-R provides T scores for four subscales: Oppositional Defiance, Cognitive, Hyperactivity, and ADHD. Scores in the clinical range (T score > 60) suggest symptoms that are problematic (moderately atypical), while scores in the at-risk or borderline range indicate potential problems that should be investigated further (mildly atypical).

Social Responsiveness Scale (SRS)

The parent(s) of participants were also asked to complete the Social Responsiveness Scale (SRS; Constantino & Gruber, 2005), which also provides T-scores and was used to assess general level of autistic symptomology. Since the participant pool was recruited through the Johnson Lab, which is focused on Autism Spectrum research, this measure was included to screen for participants with autistic features. Children and adolescents with an Autism Spectrum Disorder may present with attentional difficulties, and since the current study was focused on typically developing children and adolescents, it was important to ensure that participants did not have autistic features. The SRS subscales include awareness, cognition, communication, motivation, and autism mannerisms. Similar to the CRS-R, scores in the clinical range indicate moderate atypicality, while scores in the at-risk or borderline range indicate mild atypicality. These subscales were examined for scores in the clinical range. However, only the SRS total score was examined in relation to CAST performance.

Wechsler Abbreviated Scale of Intelligence (WASI)

In order to characterize cognitive abilities that may be associated with or contribute to performance on the attention tasks, the *Wechsler Abbreviated Scale of Intelligence* (four subtest WASI, Wechsler, 1999) was used as a standardized measure of estimated level of intellectual functioning. In the interest of time, as well as ethical and psychometric issues surrounding frequency of repeat psychological testing, intellectual testing was not repeated if scores were obtained on a previous visit to the lab within the past two years. If psychological testing had occurred outside of the lab within the past two years, parents were given the option to provide consent for release of information in order to allow us to obtain the psychological assessment results. If parents and participants consented, we requested results of intellectual testing. Therefore, intellectual testing was only repeated if scores were not available or obtained more than two years ago.

Combined Attention Systems Test (CAST; developed by Mike Lawrence)

Total time required to complete the CAST was approximately 15 minutes. The task was presented in several blocks so that participants had opportunities for several brief breaks during this portion of the session. The task was completed on a MacBook with a 13” screen, with images appearing on a white background. Please see Figure 2 for a flow chart of the CAST.

Participants were seated approximately 64 cm from the computer screen. Each trial began with an arrow, subtending 1 degree presented at fixation, which pointed either left or right and informed the participant of the likely (accurate prediction on 75% of trials) location of the subsequent target (see Figure 3). At the beginning of the trial a shape (subtending 2 degrees) was presented simultaneously with and surrounding the arrow. The shape was either a square or circle and the identity informed the participant whether they would hear a tone prior to the

presentation of the subsequent target. For half of the participants, the circle meant they would hear a tone while the square meant they would not hear a tone, and vice versa for the other participants.

Following presentation of the shape-arrow combination, a random exponential interval (aka. a non-aging interval) would elapse with a minimum of 1 second and a mean of 2 seconds. On "tone present" trials, a 50ms 440Hz tone was then presented; on tone absent trials, no tone was presented. Regardless of tone presence/absence, the target was presented 1 second following the end of the random exponential interval. This insured that the shape-arrow combination did not temporally predict the onset of the target, as this was an important limitation of the ANT. The target was an animated fish pointing either left or right (see Figure 4) and participants were instructed to indicate the direction that the fish was pointing by pressing either the left-hand or right-hand trigger button on a logitech USB gamepad.

The target remained on the screen until a response was made or 2 seconds elapsed, whichever came first. Participants were instructed to try to avoid making errors, but the speed of responding was emphasized. To enhance the game-like nature of the task and to reinforce the emphasis on response speed over accuracy, the participants' response time was presented in the center of the screen for 1 second following response. On rare trials when participants failed to make a response, the word "MISS" appeared. The target fish were presented either 5 degrees to the left or right of fixation, and could be either presented alone or in a school of fish (one above, one below, one to the right, one to the left, all separated by 0.2 degrees). When presented in a school of fish, the surrounding school (i.e., flankers) could be pointing either the same direction as the target fish or in the opposite direction (see Figure 5).

Thus, variables manipulated are: arrow (3 valid for every 1 invalid), tone (present,

absent), target direction (left vs. right), target location (left vs. right), and flankers (none, congruent, incongruent). A full factorial combination of these variable yields $4 \times 2 \times 2 \times 2 \times 3 = 96$ trial types. Of these 96 trial types, a random 32 were selected for each participant to serve as practice. Following practice, the full set of 96 trial types were presented in random order and split into 3 blocks of 32 trials each.

There are four main effects that can be examined with the CAST data and these correspond to specific aspects of endogenous attention, which is characterized as being voluntary and goal-directed attention. This is in contrast to exogenous attention, which is often considered involuntary and automatic. 1. Arrow: comparison of trials with valid versus invalid trials provide information about endogenous *spatial orienting*. 2. Tone: comparison of trials with a tone present versus tone-absent provide information about endogenous *temporal orienting*, also referred to as *alerting*, 3. Flanker: comparison of trials with congruent and incongruent flanker stimuli provide information about endogenous *spatial cuing* and *executive function*, and 4. Spatial Stroop: comparison of trials with congruent and incongruent spatial stroop provide information about *executive functioning*. For statistical analyses, the target direction and target location variables will be transformed into "spatial Stroop congruent" (right-sided & right-pointing targets, left-sided & left-pointing targets) versus "spatial Stroop incongruent" (left-sided & right-pointing targets, right-sided & left-pointing targets).

Design and Analyses

Due to the fact that reaction time (RT) data was measured multiple times within each participant and that the variability across these responses is important data, collapsing the multiple RTs to a participant mean (as occurs during the computation of an ANOVA) was not desirable. Therefore, a tool which accounts for the hierarchical nature of the raw RT data (found

within participants) was used, and is known as Mixed Effects Modelling (MEM). MEM provides estimates of three parameters: the population mean RT, the variance that a participant deviates from the population mean RT, and the variance of error. For more details on MEM, see Lawrence and Klein (2012). Since age, intellectual quotient, and scores from the CRS-R and SRS (continuous variables) were used as predictor variables, “Generalized Additive Modelling” (GAM) was incorporated into the Mixed Effects Modelling. General Additive Models assume that the mean of the dependent variable is dependent on an additive predictor through a nonlinear link function (SAS, 2011). Including these analyses permitted us to examine how specific participant characteristics were related to performance on the CAST.

Mixed effects modelling was used to analyze both response time (RT) and error rate (ER) data (employing a logit binomial link for the latter), treating participant as a random effect and arrow, tone, flanker, and spatial Stroop as fixed effects. Evidence for main effects, two-way and three-way interactions between the fixed effects were interpreted by examining the likelihood ratios that result from MEM (Lawrence & Klein, in press). These likelihood ratios are intended to serve as continuous metrics of evidence, rather than the more common null-hypothesis significance test where the result is either significant or non-significant. A guide for qualitative interpretation has been provided by Royall (1997), who suggested a value of 3 bits (i.e., a likelihood ratio of 8) as reflecting pretty strong evidence for one hypothesis over another, and a value of 5 bits (i.e., a likelihood ratio of 32) as reflecting strong evidence for one hypothesis over another.

Data Pre-Processing

Of the thirty-one participants who completed the study, seven had data that was unusable. One participant (16 years old, female) was excluded for having worse-than-chance performance

(97% errors, suggesting she was choosing the left key when the target was pointing right and the right key when the target was pointing left despite straight-forward correct response mappings). Two participants (11 years old, male; 13 years old, male) were excluded for having error rates that were not different from chance (42% and 50%, respectively). One participant (8 years old, male) was excluded for having a high rate of responding before the target appeared (early responses on 24% of trials; contrast with maximum of 7% among all other participants). Several participants with elevated scores on the behavioural characterization measures considered were excluded since the current project was focused on typically developing children and adolescents. One participant (12 years old, female) was excluded due to a Conners Hyperactivity T score of 66, which is classified as moderately atypical. One participant (12 years old, female) was excluded due to a Conners Cognitive T score of 61, which is classified as mildly atypical. One participant (11 years old, female) was excluded due to a SRS Autistic Mannerisms score of 67, which is classified as mild to moderately atypical.

Data for the twenty-four participants who were included in the final sample was pre-processed by trimming outliers. The procedure used for excluding outliers was as follows: For each participant, a linear regression was used to predict RT as a function of response accuracy for each of the predictor variables: arrow, tone, flanker, and "spatial stroop. Using this regression, Cook's distance, which combines the information of leverage (how far an independent variable deviates from its mean) and residual of the observation (difference between the predicted value and the actual, observed value) was computed for each observation. Those whose distance exceeded a criterion distance (computed as 4 divided by the number of observations used to compute the regression, as suggested by Bollen et al., 1990) were excluded from subsequent analyses. This procedure excluded approximately 7.5% of trials overall. Similar

results as those presented in this report are obtained when more traditional (yet questionable) outlier rejection procedures (e.g., excluding, within each participant, trials when the RT's absolute deviation is greater than 2 standard deviations from the mean) are employed. See Figure 6 for each participant's trimmed reaction time graphs. Analysis of response times included only those trials on which participants made an accurate response.

Results and Interpretation

Demographic Characteristics

The final sample consisted of twenty-four participants, which included 15 males and nine females with ages ranging from 8-16 ($M = 11.6$ years). Twenty participants were right-handed and four were left-handed. Participants had a mean full-scale IQ score of 113.3 ($SD = 14.9$), a mean verbal IQ score of 114.4 ($SD = 13.1$), and a mean performance IQ score of 112.1 ($SD = 15.6$). No participants in the final sample scored in the clinically significant range on either of the two questionnaire measures (Social Responsiveness Scale and the Conners Rating Scale-Revised) as these participants were removed in the pre-processing stage.

Analyses of Main Effects

A main effect of the Alerting network (i.e., tone) was found for both participant RT (Bits = 19.43) and participant ER (Bits = 55.13). As shown in Figure 7, participants had smaller RTs and made fewer errors for valid arrow trials versus invalid arrow trials. A main effect of the Orienting network (i.e., arrow) was found for participant ER (Bits = 41.84) but not for participant RT. As seen in Figure 8, participants made fewer errors for tone present trials than for tone absent trials. However, their RTs were not significantly different for tone present versus tone absent trials.

A main effect of Spatial Stroop was also found for both participant RT (Bits= 29.20) and ER (Bits= 16.22). As shown in Figure 9, participants had smaller RTs for congruent spatial stroop trials than for incongruent spatial stroop trials. Participants also made fewer errors for congruent spatial stroop trials than for incongruent trials. Finally, a main effect of Flankers was found for both participant RT (Bits= 152.29) and ER (Bits= 67.09). As shown in Figure 10, participants had smaller RT for congruent flanker trials, and made fewer errors for congruent flanker trials when compared to incongruent flanker trials. These findings provide support for the validity of the CAST in the age range examined in the current study.

Analyses of Interactions

As shown in Figure 11, in addition to the main effect of Alerting, older age was associated with faster reaction times for both tone absent and tone present trials (Bits = 5.22). As shown in Figure 11, the relationship between age and RT was generally linear. Participants were consistently faster for tone present trials than for tone absent trials. However, the effect of tone present trials (e.g., the size of the difference between tone present vs. tone absent trials) was larger for younger children relative to older children. This effect is seen clearly in Figure 12, which depicts the difference scores for tone present and absent trials and displays how younger children were more affected than older children.

As shown in Figure 13, in addition to the main effect of executive control, older age was associated with faster reaction times for both congruent and incongruent spatial stroop trials (Bits = 6.83). As shown in Figure 13, the relationship between age and RT was linear. Participants were also consistently faster for congruent spatial stroop trials than for incongruent trials. However, as shown in Figure 14, the difference between congruent and incongruent trials was larger for younger children relative to older children.

As shown in Figure 15, there was also positive evidence for a relationship between errors on orienting trials and Conners T-scores (overall ADHD score; Bits = 4.20). Using the log-odds of error scale, a 50% error rate corresponds to a value of 0, a 0% error rate to a value of $-\infty$ and a 100% error rate to a value of $+\infty$. In this way, a log-odds of error score of -5 is approximately 1% error, a score of -4 is approximately 2% error, -3 is approximately 5% error, -2 is approximately 12% error, and -1 is approximately 27% error.

This relationship indicated that participants with higher scores (more parent-reported attention problems) on the Conners demonstrated the highest rate of errors on orienting trials for valid arrow trials. Shown in Figure 15, the comparison of errors for valid versus invalid trials indicates that participants with higher Conners scores made a higher proportion of errors on valid trials, while all participants had a similar rate of errors for invalid arrows. In Figure 16, the log-odds of error scale is now presented as a difference score, where the value was computed by simple subtraction. Therefore, Figure 16 shows how the differences between error rates for valid versus invalid orienting effects is larger for participants with higher Conners ADHD scores.

Non-significant relationships: RT

There were no relationships between participant age and orienting effects. There was also no relationship between participant age and flanker effects. No interactions were found between participant questionnaire scores (both SRS questionnaire and Conners questionnaire) and any of the effects (i.e., alerting, orienting, spatial stroop, and flanker). Finally, none of the participant IQ scores (Verbal IQ, Performance IQ, and Full Scale IQ) yielded any relationships with any of the effects.

Non-significant relationships: Error rate

There were no relationships for any of the main effects between participant error rate and participant age, SRS questionnaire scores, CRS-Cognitive Index scores, WASI-Verbal IQ,

WASI-Performance IQ and WASI-Full Scale IQ. For the CRS-ADHD Index score, only participant error rates for the alerting effect yielded a relationship (as described above), while the other effects did not.

Discussion

The primary aim of the current study was to examine the validity of a new attention measure, the CAST, in children and adolescents. Specifically, the aim was to evaluate expected main effects of the three attentional networks as well as any potential interactions between these networks and several demographic variables of interest, including age, IQ, parent-reported attentional abilities, and parent-reported autistic features. These latter analyses were important in order to begin to characterize how other participant variables relate to performance on the CAST.

In general, it was expected that main effects would be present for all variables (arrow , tone, flanker, and spatial stroop). It was also expected that older children would perform faster than younger children for all types of trials. Since executive functioning is known to develop with age, older participants were expected to perform better (lower RT and fewer errors) than younger children for trials requiring these skills (flanker and spatial stroop trials). It was also expected that participants with lower CRS-R scores and lower SRS scores would have faster RT scores and lower error rates compared to those with higher scores. Participants with higher IQ scores were also expected to perform faster and have fewer errors.

Main Effects

Main effects were found for all four conditions for participant RT and ER, except for participant RT for the orienting network. These results are consistent with our hypotheses and provide support for the idea that the three attentional networks respond best when provided with

support (i.e., warning tones that something is about to occur, orientation towards the place this will occur, and less conflict for the brain to overcome).

Interactions between main effects and characterization measures

As expected, there were significant interactions between the main effects and participant age. Specifically, participant age interacted with participant RT for alerting (tone present/absent) and executive control (spatial stroop) effects. Interestingly, these results are consistent with Rueda et al. (2004) who suggested that alerting and executive functioning develop throughout childhood, but that orienting may be stable after infancy. Similarly, we found that both the alerting network (i.e., tone) and one measure of the executive functioning network (i.e., spatial stroop) were associated with age.

There was one significant interaction for the CSR-R. The scores for the CRS-R's ADHD subscale interacted with participant error rates for orienting effects. All other interactions were non-significant. In other words, across age, IQ scores, and CRS-R and SRS questionnaire scores, no other participant characteristics were related to either RT or ER for any of the CAST conditions. The majority of these findings are in contrast to our hypotheses that these characteristics would interact with participant performance.

Alerting

Also in accordance with our hypothesis, there was a main effect of alerting for participant reaction times. However, this same effect was not found for participant error rates. In other words, hearing a tone prior to the stimulus appearing on the screen did not increase accuracy, nor did not hearing a tone decrease accuracy, although the tone did result in faster reaction times. An interaction was also found between participant age and orienting effects for participant RTs. Older participants had smaller differences between their RT scores for tone present and tone

absent trials, while younger participants had larger differences between their RT scores. Thus, age appears to be an important factor in the examination and interpretation of alerting effects.

Tone trials examine the alerting network. This may have been especially relevant in the present study, as participants spent a long period of time in front of the computer completing other tasks for the larger study. Since participants completed the computerized testing battery in a randomized order, the CAST was administered at various time points during the study visit. For some participants, it is possible that they may have been fatigued or that their attention was waning by the time they completed the CAST. It is also possible that this may have been more of a factor for younger, relative to older children. Analyses of these “timing” effects were beyond the scope of the current study, but it would be interesting to attempt to examine if this affected performance. A possible future direction would be to administer the CAST on its own in comparison to completing it along with other tasks to see if this effects participant performance.

Spatial Orienting

In accordance with the hypothesis, there was a main effect of spatial orienting for both participant reaction times and error rates. There was one interaction for spatial orienting; specifically the CRS-R ADHD subscale score interacted with participant error rates for the orienting effect. However, there were no relationships between spatial orienting and age, SRS, other CRS subscales, or IQ scores. It appears as though while trials with valid orienting cues resulted in faster reaction times and lower error rates, participant age, IQ scores, parent reported autistic features and parent reported attention features did not interact with the effect of spatial orienting.

Executive Functions

As expected, there were main effects of spatial stroop and flanker for both participant RT and error rates. For both conditions, participants were consistently faster for congruent trials, compared to incongruent trials. In addition, the main effect for spatial stroop interacted with age, such that younger participants had larger differences between their RT scores for congruent spatial stroop trials while older participants had smaller differences. Younger participants were more affected by incongruent spatial stroop trials than congruent spatial stroop trials, leading to longer response times for incongruent trials. Older participants also took longer to respond when the spatial stroop was incongruent, they were not as affected, meaning their RTs for incongruent spatial stroop trials were closer to their RTs for congruent spatial stroop trials. In contrast, none of the participant characteristics (age, IQ, Conners and SRS scores) were associated with flanker effects. This suggests that the flanker effect is consistent across participants regardless of age and the other characteristics examined in the present study.

Validity of the CAST for Child and Adolescent Participants

Since the CAST was designed to examine attention in children and adolescents, it was important to first determine how well the CAST measures the attentional networks in typically developing children. To examine this task in children and adolescents, we recruited a sample of typically developing children between the ages of 8 and 16. For children and adolescents of this age, no difficulties were noted while completing the CAST. However, it should be noted that nearly all participants who completed the CAST for this study also completed several other tasks during their study visit, most of which were interspersed before and after the CAST. It is possible that some children may have experienced fatigue during the computer tasks. The CAST is designed to be very child-friendly, utilizing simple, colorful stimuli, and thus we expect that this

helped to offset any fatigue or boredom. The participants were also offered breaks throughout the visit and were provided a snack during break times.

Overall, the presence of main effects for all three attentional networks (and all four conditions) suggests that the CAST is able to measure these constructs within the age range included in this study. These results seem to fit best with content validity; that is, the CAST appears to measure all of the constructs it is intended to measure. Of course, there are other types of validity (e.g., construct validity) that we did not examine in this study and will need to be considered in future studies of the CAST in children and adolescents.

Excluded Participants

The seven participants removed from the final sample were a heterogeneous group. There was no particular pattern of age, IQ, or other demographic information that would suggest that the CAST is not suitable for certain participants. For three of the participants removed, the reason for removing them was due to questionnaire results which placed them in ranges that indicated mild to moderate elevations. We were conservative with these measures in this study so that all participants represented typical development as much as possible. The four participants who had unusable data varied in age (8-16 years old), had similar IQ scores (3 participants had a Full Scale IQ score in the Average range, while the fourth was in the Superior range), were mostly male (only one female) and had different reasons for being removed from the analyses (performing worse than chance, at chance, or anticipating the targets).

Application to ADHD and School Psychology

It is of interest to note that no relationship was found between participant IQ scores and any of the variables. Thus, within the range of IQ scores represented by the present study (average to superior), IQ does not appear to contribute to performance on the CAST. It will be

important to recruit participants with a broader range of IQ scores for future studies so that we can determine if the CAST is valid for children and adolescent with lower cognitive abilities. It is also of interest to note that the Conners-ADHD score was only related to participant ER for orienting. While error rates were consistent across scores for invalid arrows, participant's with higher error rates for valid trials also had higher Conners-ADHD scores. In this sense, as participants were described as having more ADHD symptoms, they made more errors for trials when the arrows were indeed valid. It is possible that impulsivity was a factor in these trials.

Given that the CAST addresses some important limitations of the ANT-I, it would be interesting to complete a similar study comparing children with ADHD to their typically developing peers with the CAST and compare these results with Mullane et al. (2011) who only examined children with ADHD. It is interesting that the network of interest in our study, in relation to ADHD features orienting was not different between the ADHD and typical group in Mullane et al.'s study. Although the results of Mullane et al.'s study differed from the current study, this is likely due to the fact that participants in the current study were typically developing children and thus, attentional abilities were only in the normal range. Understanding and diagnosing ADHD is an important component of school psychology practice and having a research tool such as the CAST could help shed more light on the deficits of students with ADHD. Although ADHD diagnosis is based on behavioural descriptions by parents and/or teachers, it is important that we better understand how this manifests in cognitive and academic performance in individual children. The CAST may be a tool that we can use in the near future to describe individual patterns of attentional performance in children and adolescents.

Limitations and Future Directions

Although this study represents an important first step in the validation and exploration of the CAST in children and adolescents, there are some important limitations. First, the current study included a limited age range and only 24 participants. Each of the ages were not represented by a large number of participants. Ideally, more participants should be included in the sample and each age should be represented equally (e.g., ten participants who are 7 years old, ten participants who are 8 years old, etc.). Another limitation to note is that participants completing the CAST were often in the Johnson Lab at Dalhousie University for approximately two hours completing other tasks for a larger study. It would have been ideal to have participants complete the CAST at the beginning of these visits before fatigue could become a factor. However, the computer tasks were completed in a randomized order meaning the CAST was sometimes the last task the participant completed during their visit. A future direction could be to have participants complete the CAST on its own instead of within a larger study. As mentioned above, including participants with a wider range of intellectual ability, especially those with lower IQ scores, will be useful for examining the utility of the CAST for children and adolescents with lower IQ scores. It would also be interesting to examine younger children with the CAST to determine if the difference between tone present and absent trials is even larger for children under the age of 8.

However, given that all participants were school-aged children and adolescents, they are familiar with attending for several hours at a time in the classroom. As mentioned, we provided breaks whenever needed and attempted to vary tasks in ways that minimized attentional fatigue. On the other hand, participant testing was completed during the summer months when participants were out of school, and perhaps less used to concentrating for several hours at a

time. A monetary reward was used to help motivate participants who completed the study, yet it is possible that younger children were less motivated by monetary rewards. Qualitatively, older participants seemed more excited by the reward and often indicated they were saving up for a purchase and this reward would bring them closer to that purchase.

Another limitation of the current study is the small sample size. Due to the fact that seven participants were excluded, the sample size was smaller than originally anticipated. Each participant required approximately two hours of testing in the Johnson Lab, meaning that over sixty hours was spent collecting data. Given time constraints and scheduling conflicts, participants were only tested for the current study from July 2011 to September 2011. Ideally, more participants will be added to this sample in the future which will increase statistical power of the results and potentially reveal additional relationships with demographic variables.

An important future direction for the CAST is examining its reliability and other types of validity. The current study only examined one aspect of validity (i.e., content validity) and its relationship to characterization measures. Once the sample size is larger, it would also be of interest to group participants into smaller age groups (i.e., seven year olds, eight year olds, nine year olds, etc.) and compare performance between groups. By doing this, developmental trends would become more clear (e.g., differences may be found between ages eight and nine, but not seven and eight, which would support a growth in executive functioning between age eight and nine). Also, we did not examine gender effects in the current study, but this would be an interesting future direction since the incidence rate of ADHD in males is higher than in females. Another future direction would be the inclusion of additional participant characterization measures. For example, parents and/or teachers reports of executive function abilities may help

to understand performance on flanker and spatial stroop trials as they are purportedly measures of executive functions.

Conclusions

Overall, the current study resulted in important findings that will contribute to literature on attentional systems and attention tasks in typically developing children and adolescents. As predicted, participants had significantly faster RT and lower ER when responding to targets that were presented on the side of the screen they were primed to (orienting network), had faster RT when responding to targets when a tone cued them that the target would be appearing in the next second (tone effects/alerting network), had faster RT and lower ER when responding to congruent targets for spatial stroop trials (left hand pointing fish on the left hand side of the screen), and had faster RT and lower ER when targets were surrounded by congruent flankers. Participants with higher Conners-ADHD scores had higher ER for trials with valid arrows. In contrast, IQ scores and Conners-Cognitive scores were not related to participant performance in the CAST.

In conclusion, it would appear as though participant age is the most important consideration with regard to a child's performance on the CAST. In particular, some effects were more pronounced in younger children relative to older children; this was especially true for Alerting/temporal orienting (tone) and Executive Control (spatial stroop). This association between age and CAST performance will require closer examination in future studies.

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Table 1

Bits of evidence (log-base-2 AIC-corrected likelihood ratios) associated with each interaction from the analysis of error rate (ER) and response time (RT) data.

Effect	Error	RT
Arrow	19.43*	55.13*
Tone	-1.80	41.83*
Spatial Stroop	16.22*	29.20*
Flanker	67.09*	152.29*
Age: Arrow	-0.00	1.45
Age: Tone	-0.00	5.22*
Age: Spatial Stroop	-0.00	6.83*
Age: Flanker	-0.00	0.52
SRSTotal: Arrow	0.07	-0.01
SRSTotal: Tone	-0.00	-0.00
SRSTotal: Spatial Stroop	-0.00	-0.01
SRSTotal: Flanker	-0.00	-0.00
CRS-ADHD: Arrow	4.20*	-0.00
CRS-ADHD: Tone	-0.00	0.09
CRS-ADHD: Spatial Stroop	-0.00	0.17
CRS-ADHD: Flanker	0.34	-0.00
CRS-Cognitive: Arrow	0.00	-0.00
CRS-Cognitive: Tone	-0.00	-0.00
CRS-Cognitive: S.Stroop	0.54	-0.01
CRS-Cognitive: Flanker	-0.00	-0.00
WASI-VIQ: Arrow	1.81	1.91
WASI-VIQ: Tone	-0.00	0.07
WASI-VIQ: Spatial Stroop	-0.00	-0.00
WASI-VIQ: Flanker	1.42	-0.00
WASI-PIQ: Arrow	-0.00	0.18
WASI-PIQ: Tone	-0.00	-0.00
WASI-PIQ: Spatial Stroop	-0.00	-0.00
WASI-PIQ: Flanker	-0.00	-0.00
WASI-FSIQ: Arrow	0.36	1.41
WASI-FSIQ: Tone	-0.00	-0.10
WASI-FSIQ: Spatial Stroop	-0.00	-0.00
WASI-FSIQ: Flanker	-0.00	-0.00

Attention Network Task

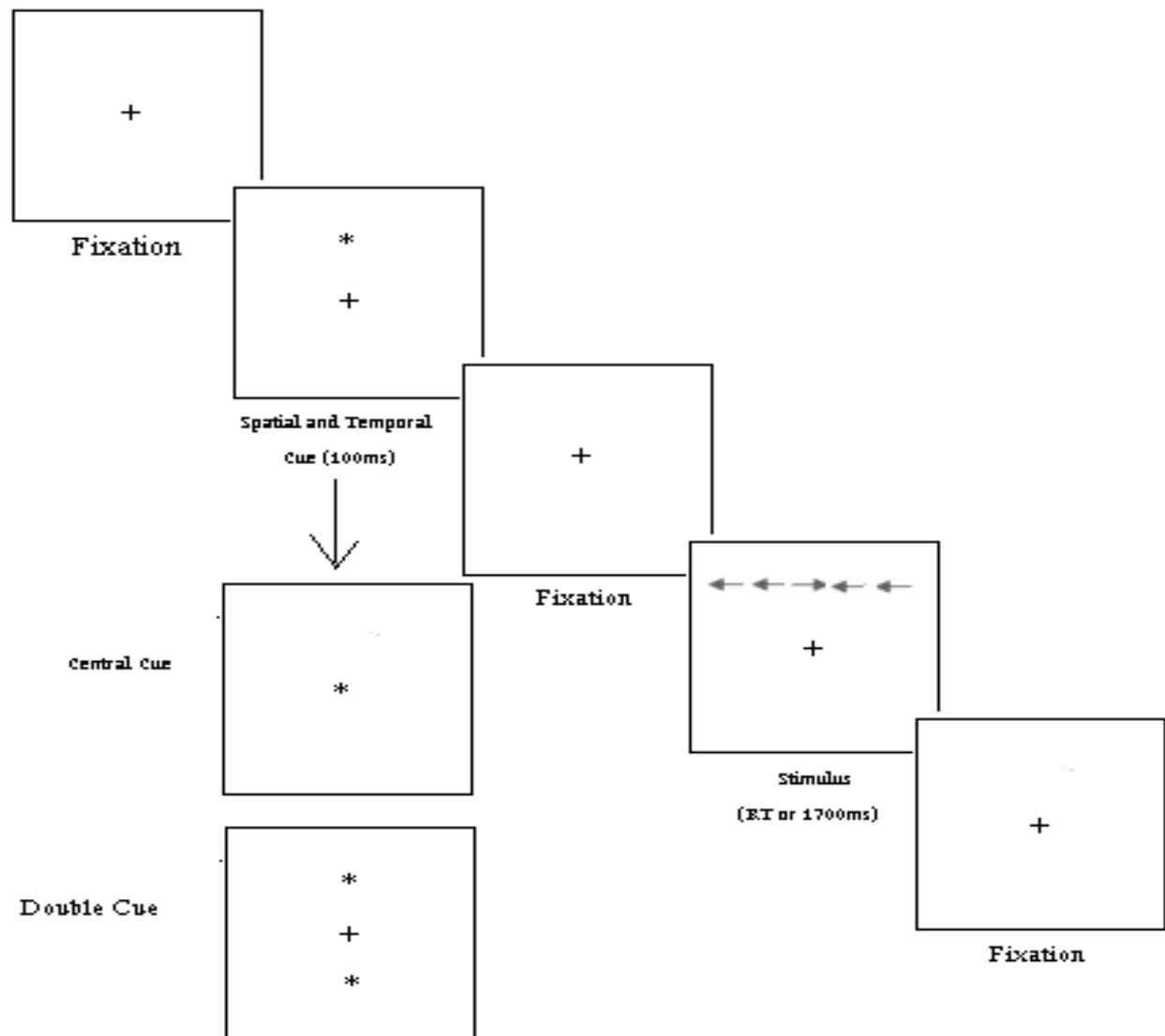


Figure 1. Flow chart of the ANT

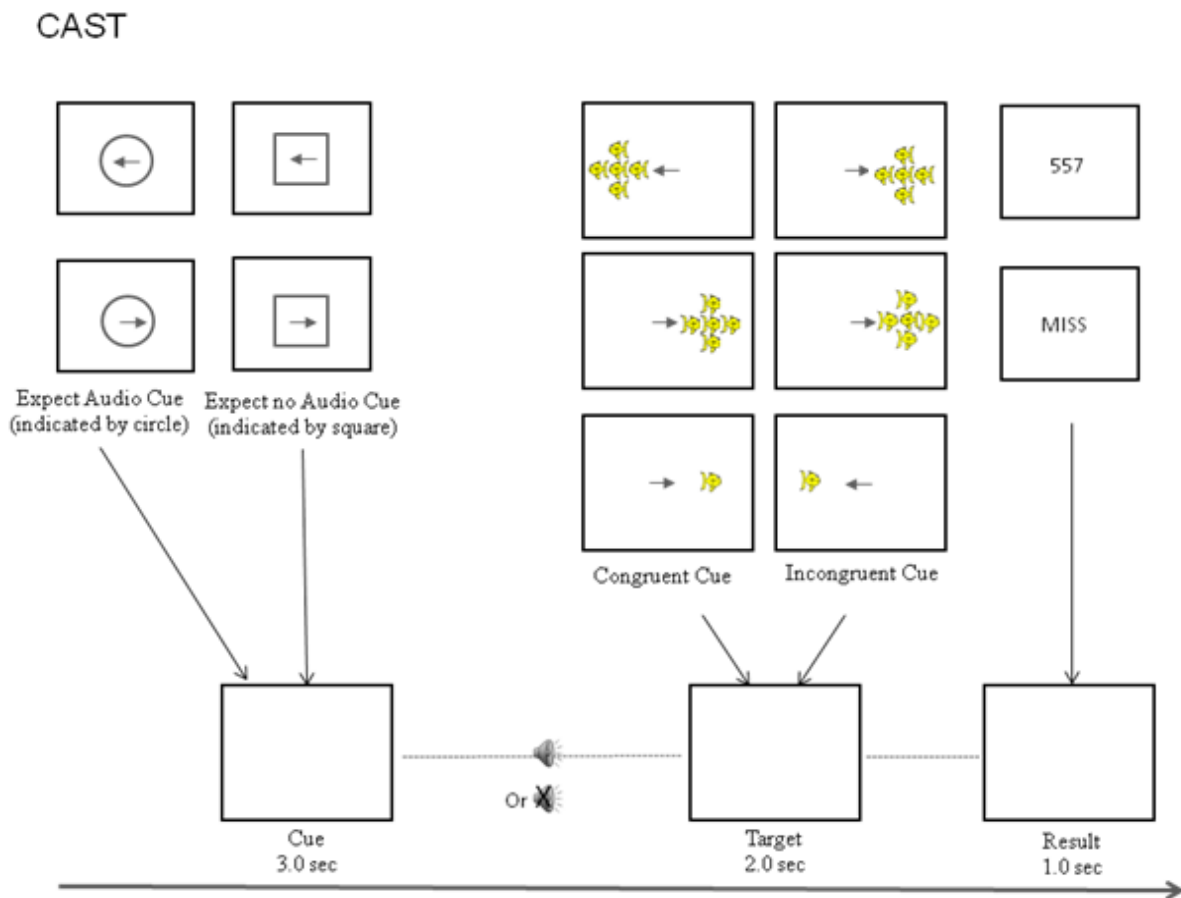


Figure 2. Flow chart of CAST.

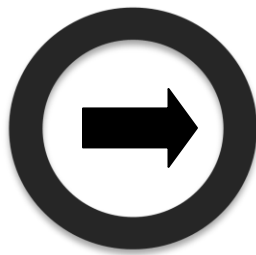
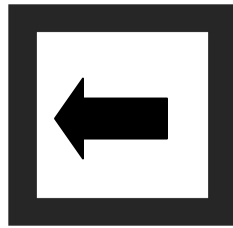


Figure 3. Example of shapes used to cue participants of tone present/absent.

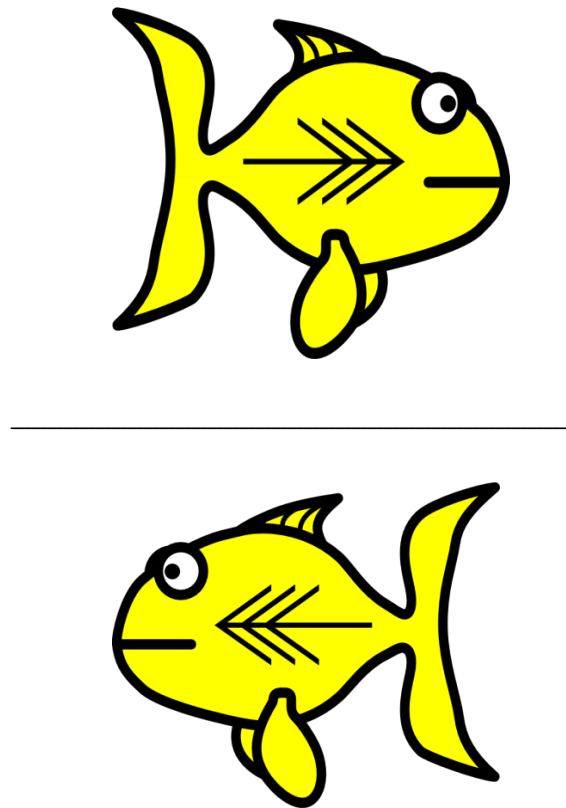


Figure 4. Animated fish used in the CAST.

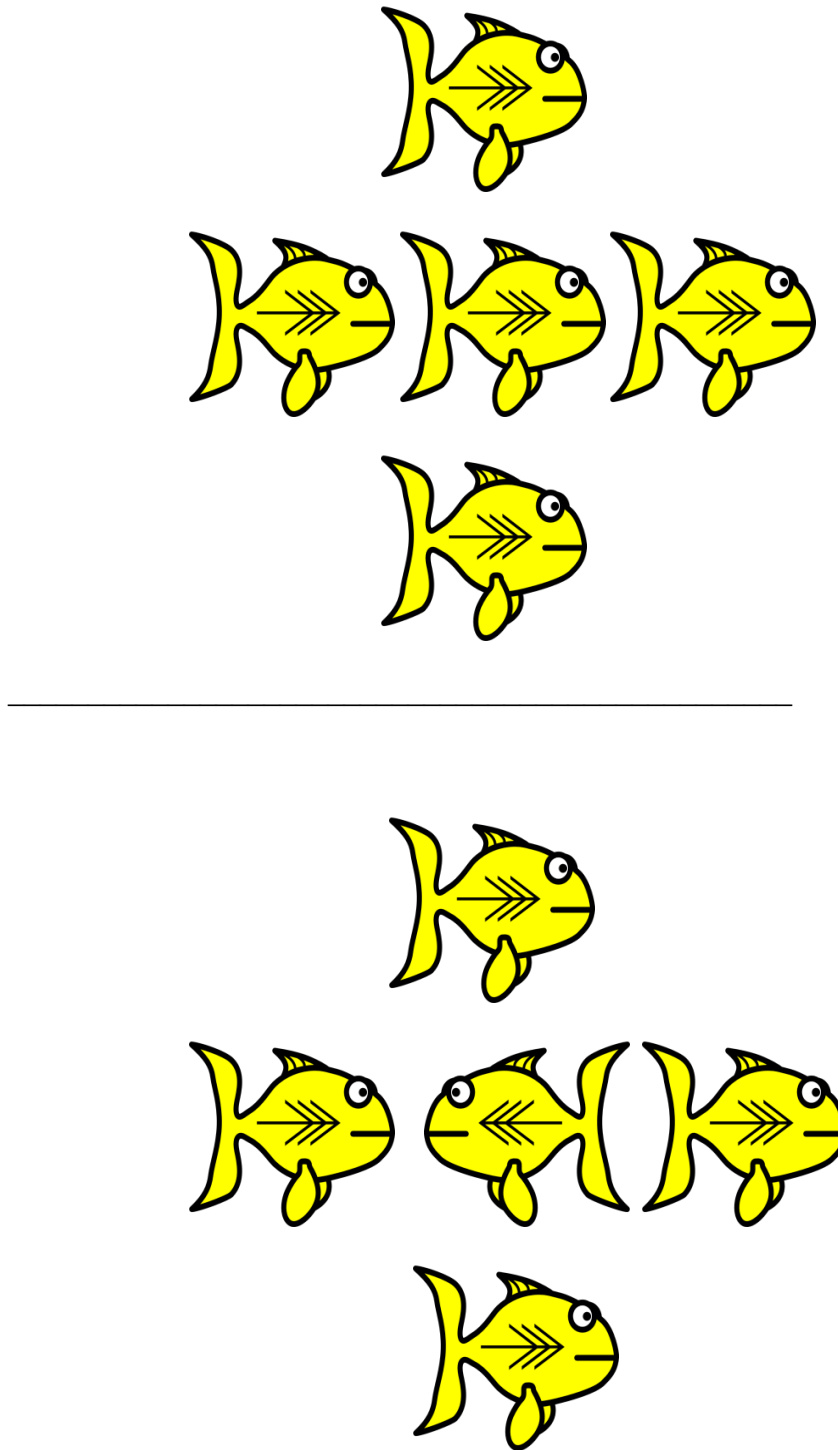


Figure 5. Example of congruent and incongruent flanker fish used in the CAST

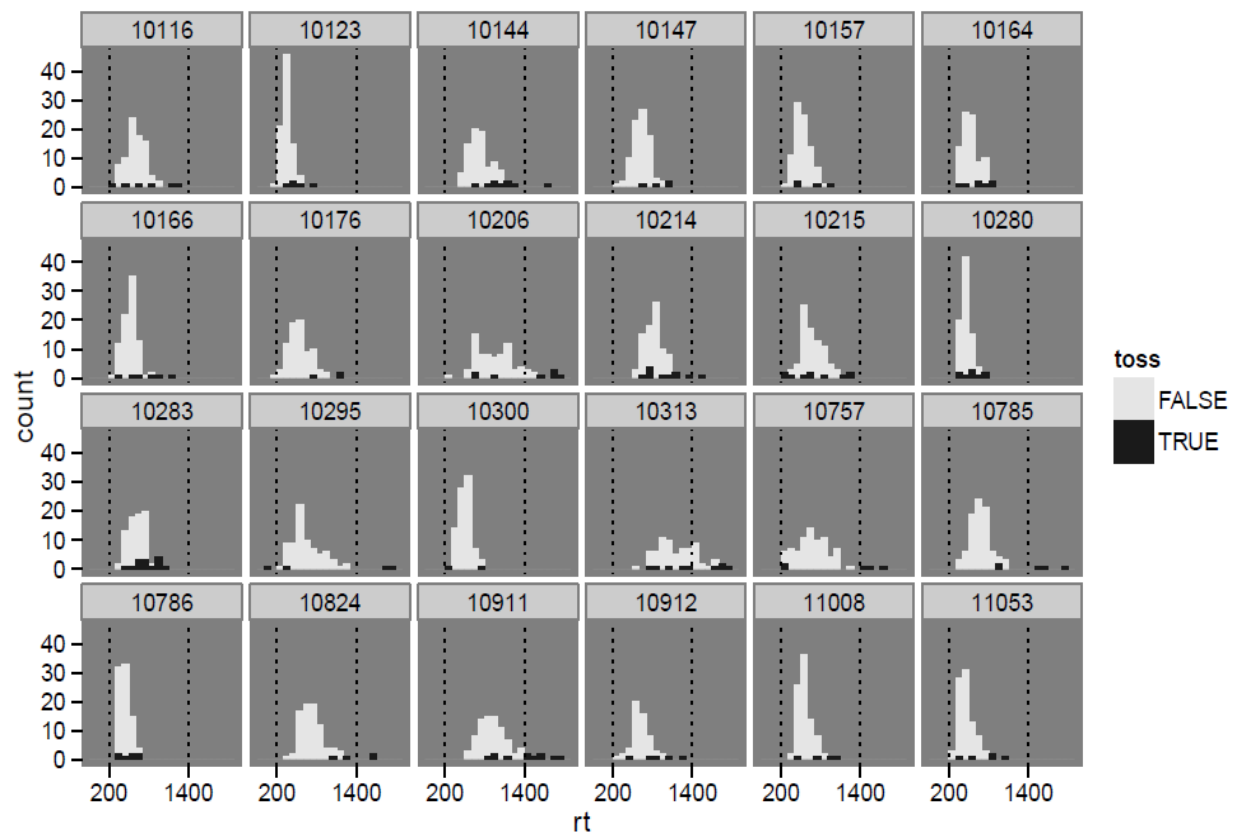


Figure 6. Reaction time histograms for each participant after labelling outliers with included RTs in grey (toss=false) and excluded RTs in black (toss=true).

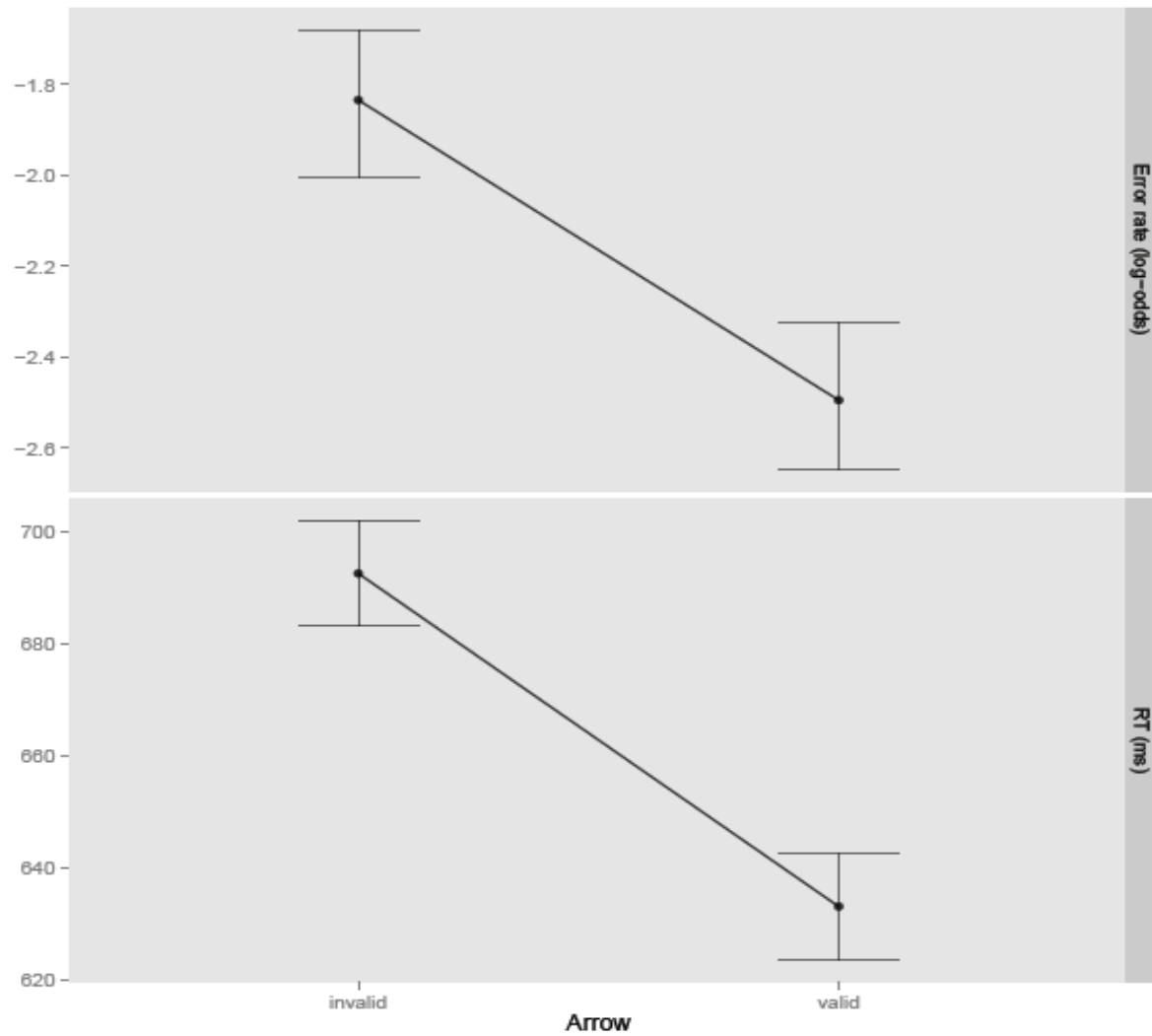


Figure 7. Main effects of Spatial Orienting: Comparison of valid and invalid arrow cue trials).

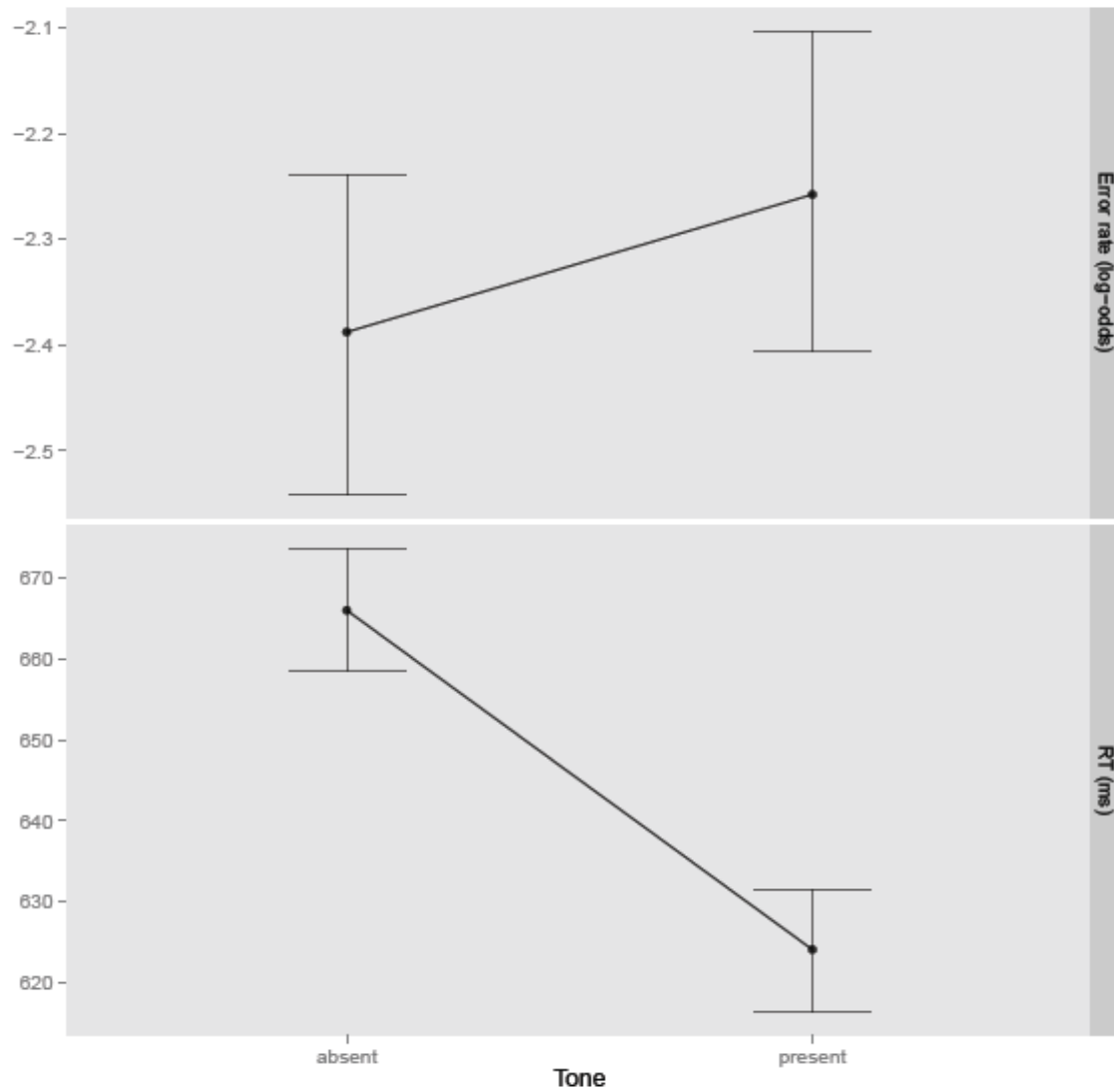


Figure 8. Main effects of Alerting: Comparison of tone present and tone absent trials.

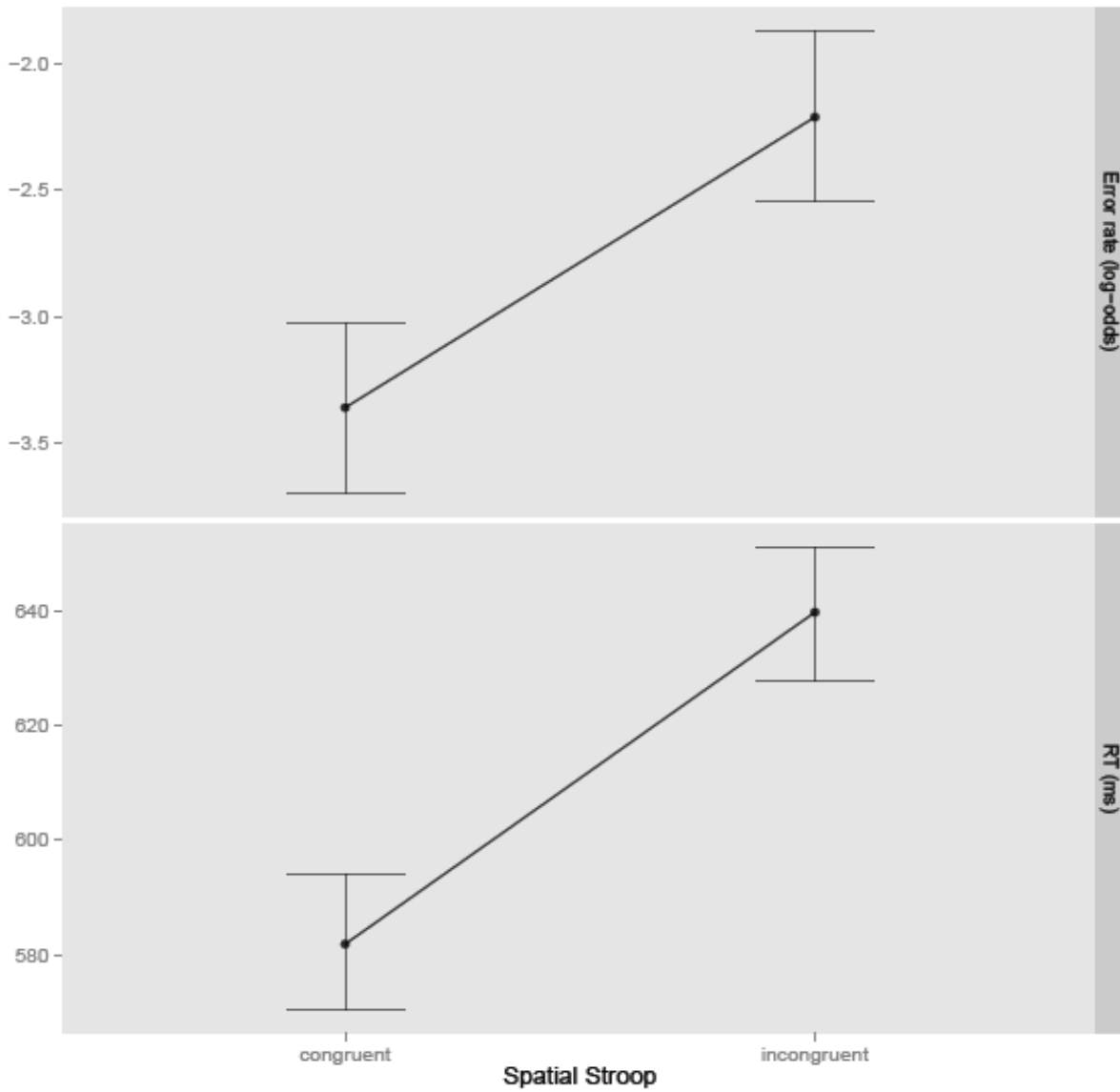


Figure 9. Main effects of Executive Control/Spatial Stroop: Comparison of congruent and incongruent trials.

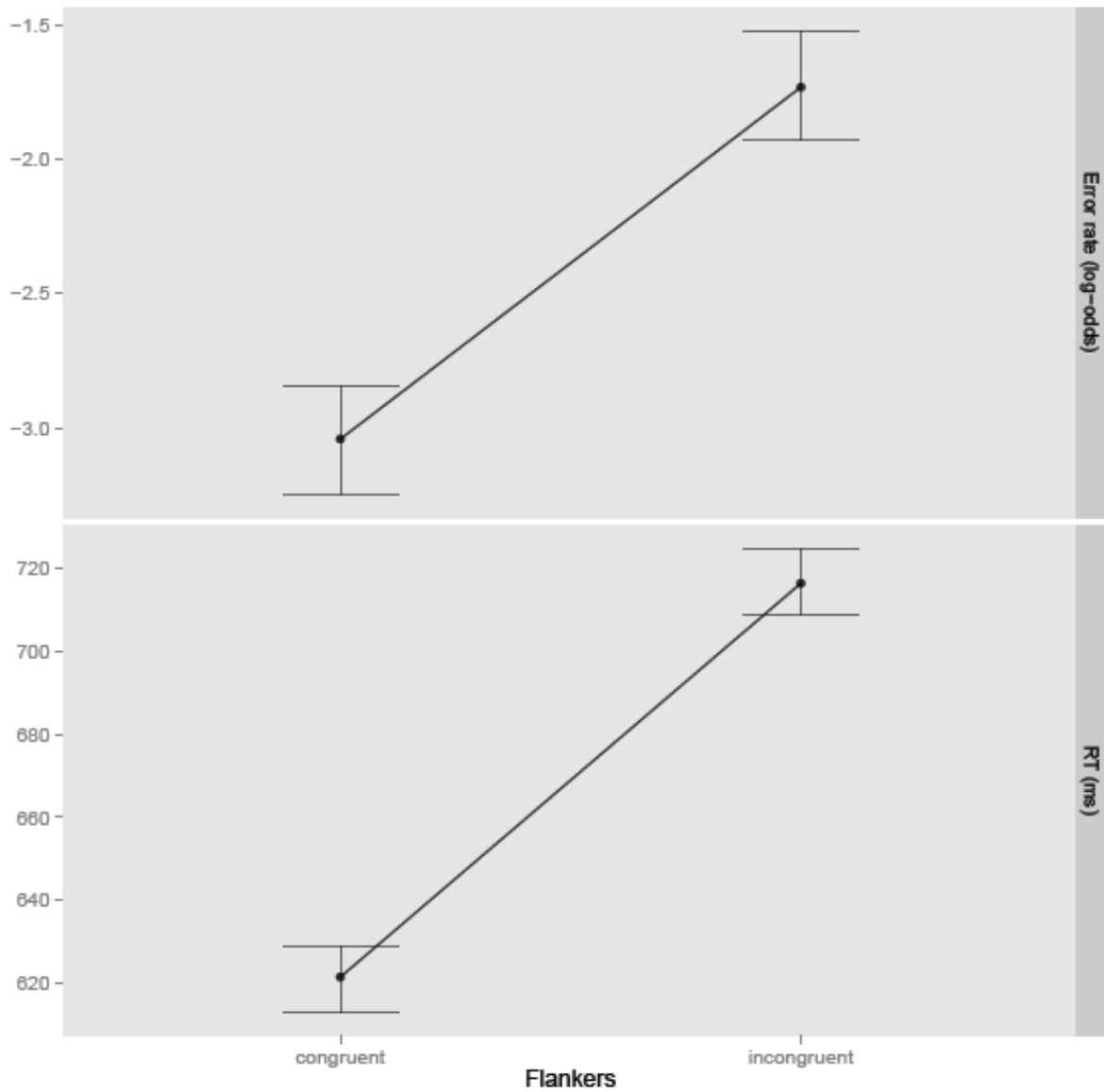


Figure 10. Main effects of Executive Function/Flankers: Comparison of congruent and incongruent trials.

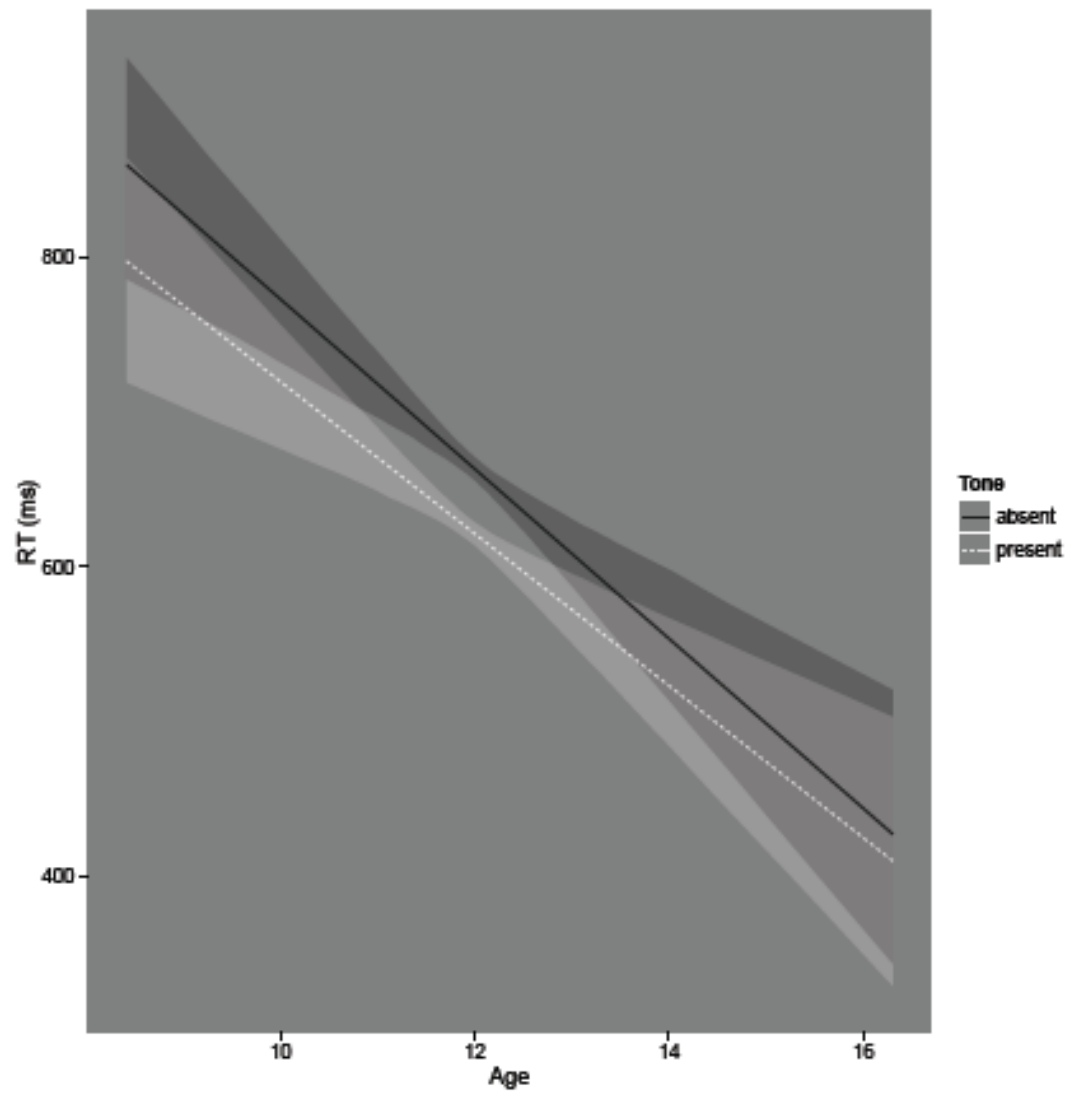


Figure 11. Participant reaction time plotted by age and grouped by tone present/absent.

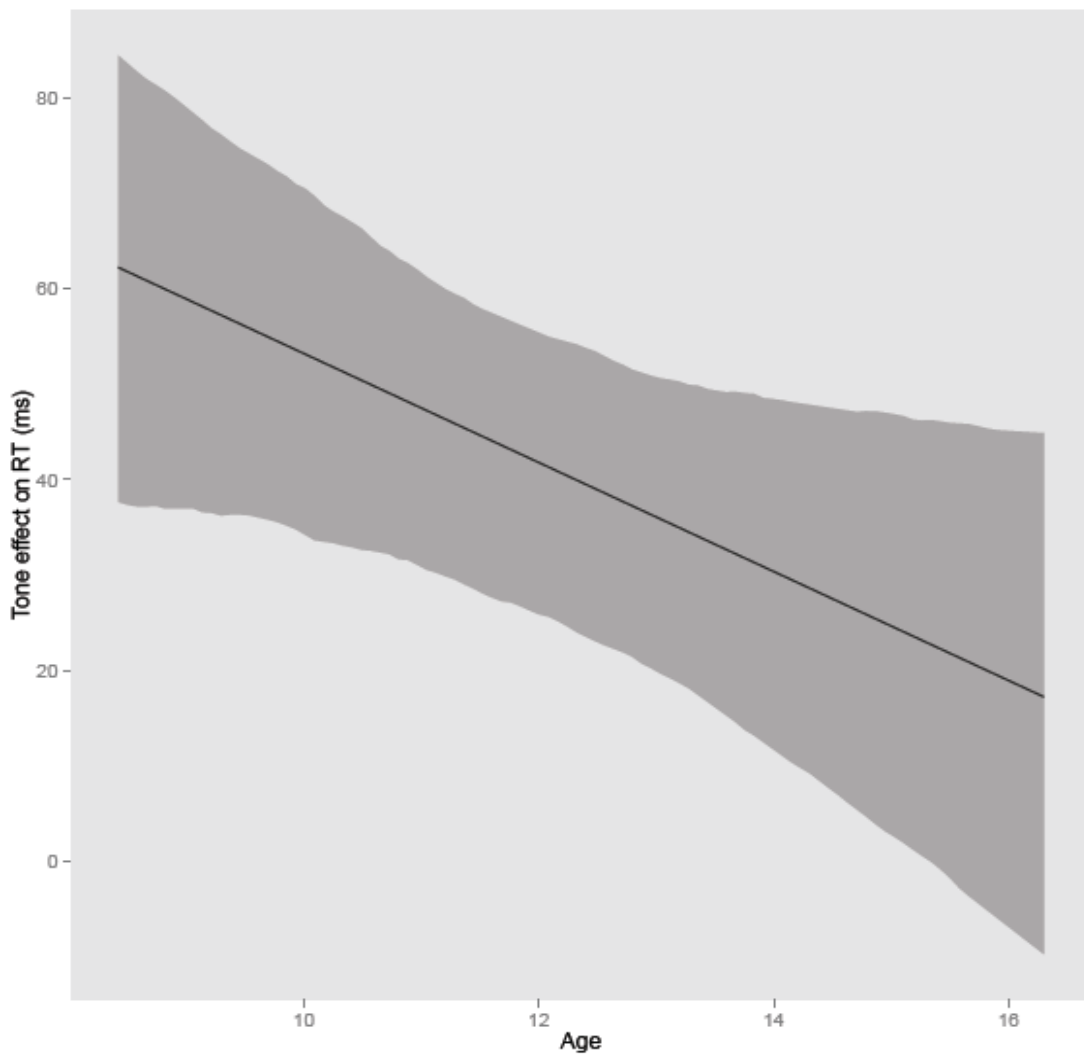


Figure 12. The difference between tone absent and tone present trials plotted by participant age.

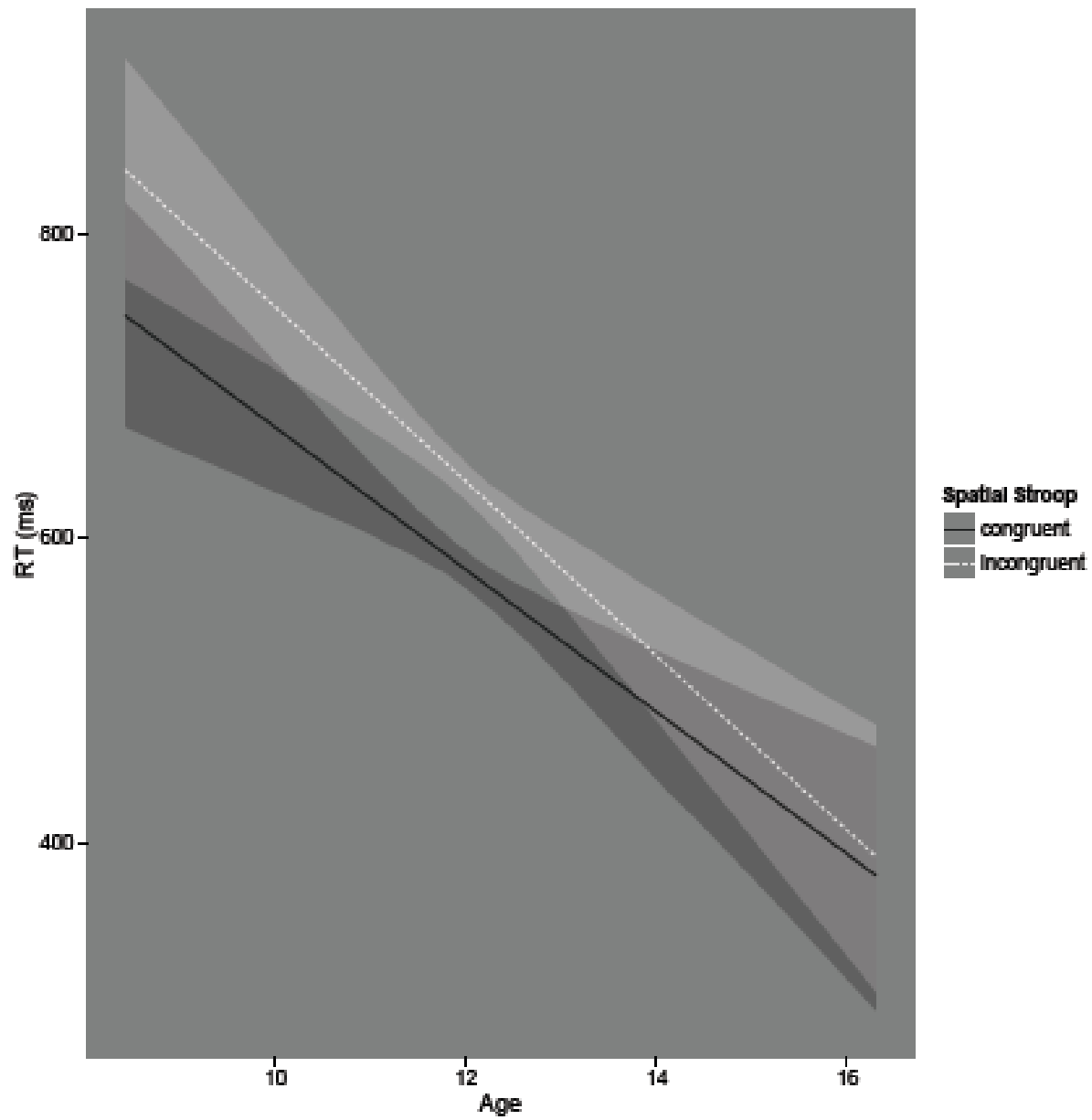


Figure 13. RTs for spatial Stroop effects plotted by participant age.

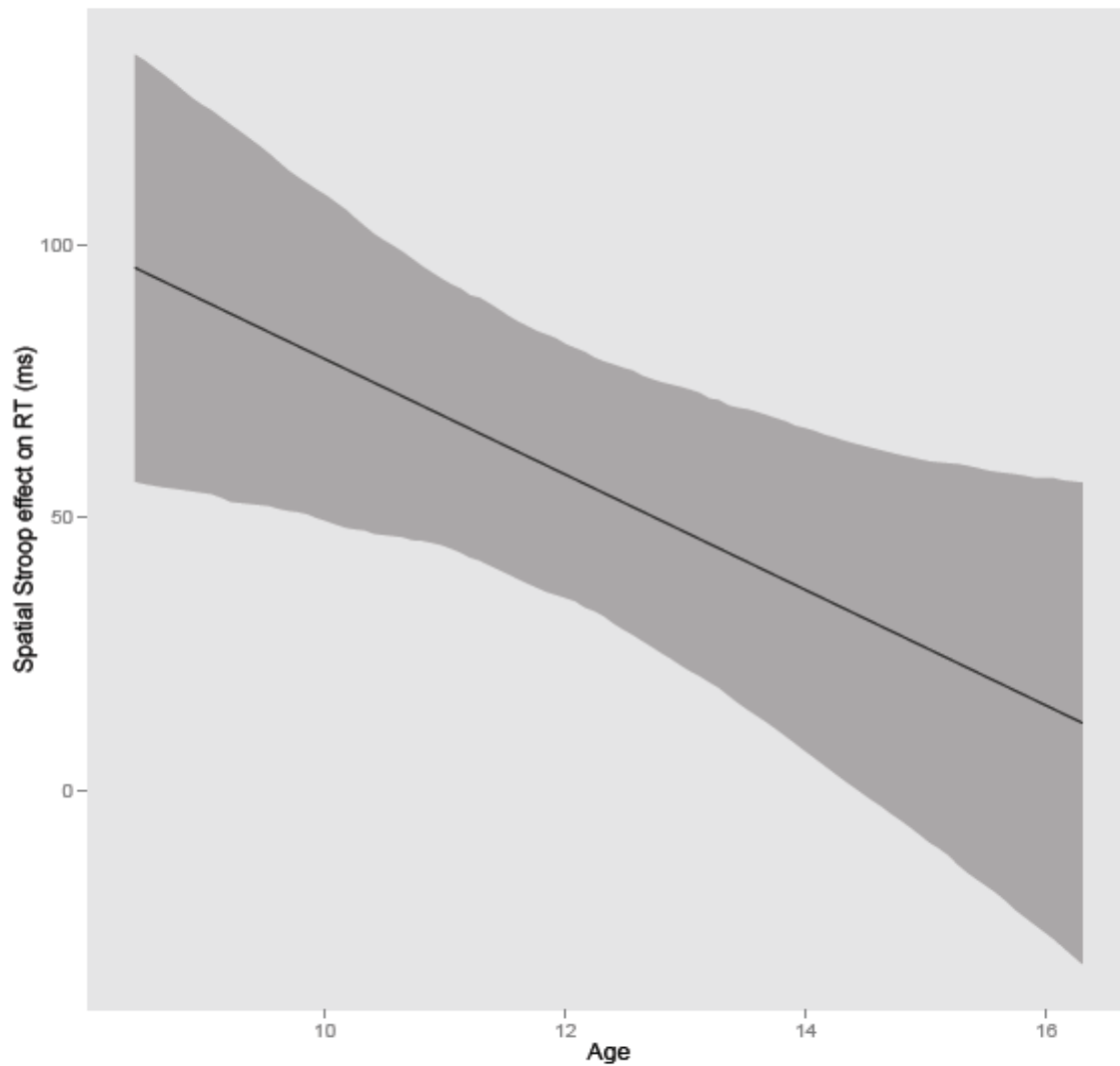


Figure 14. The difference between spatial stroop congruent and incongruent trials plotted by participant age.

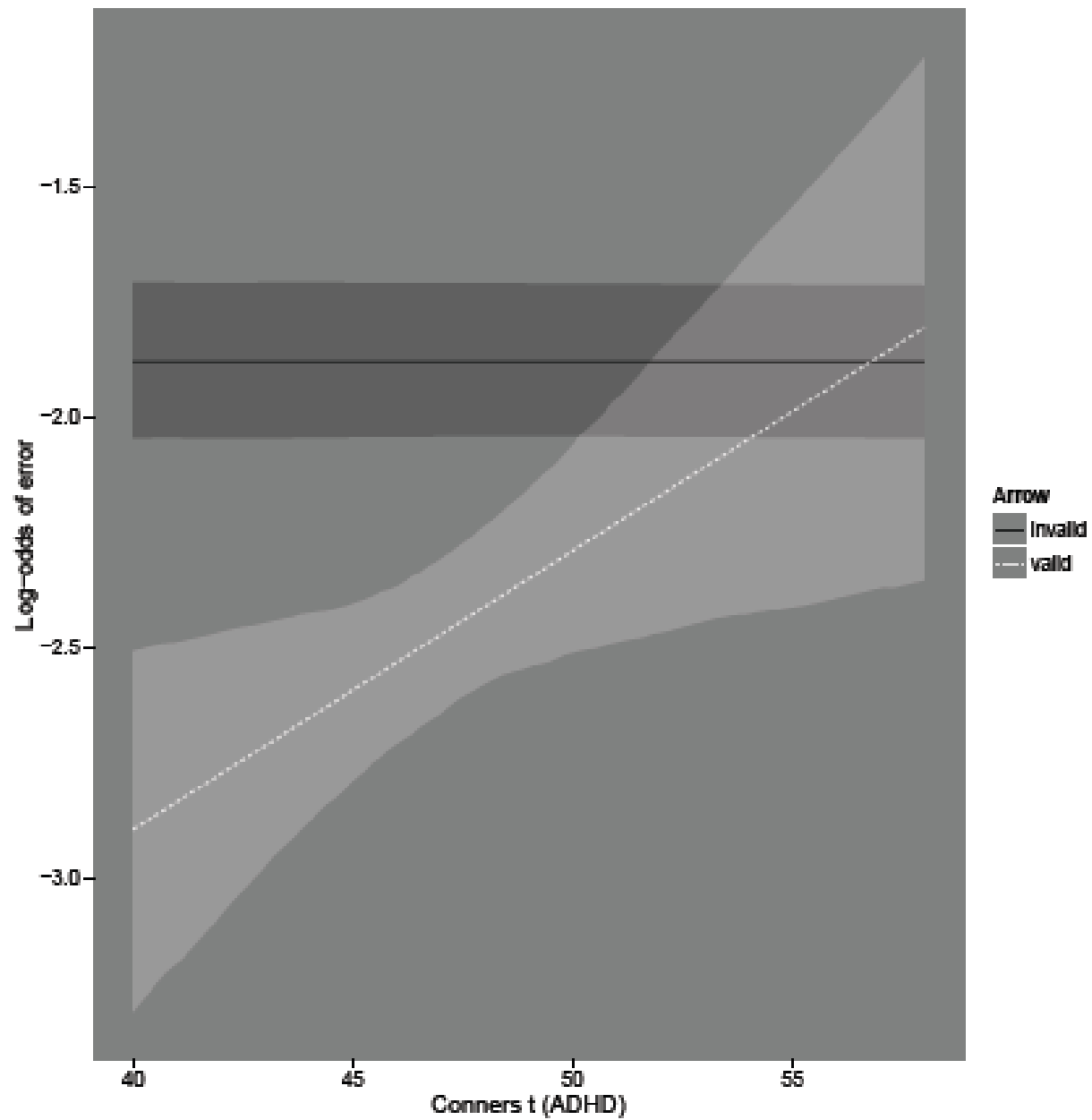


Figure 15. Orienting effects on error rates plotted by Conners ADHD T scores.

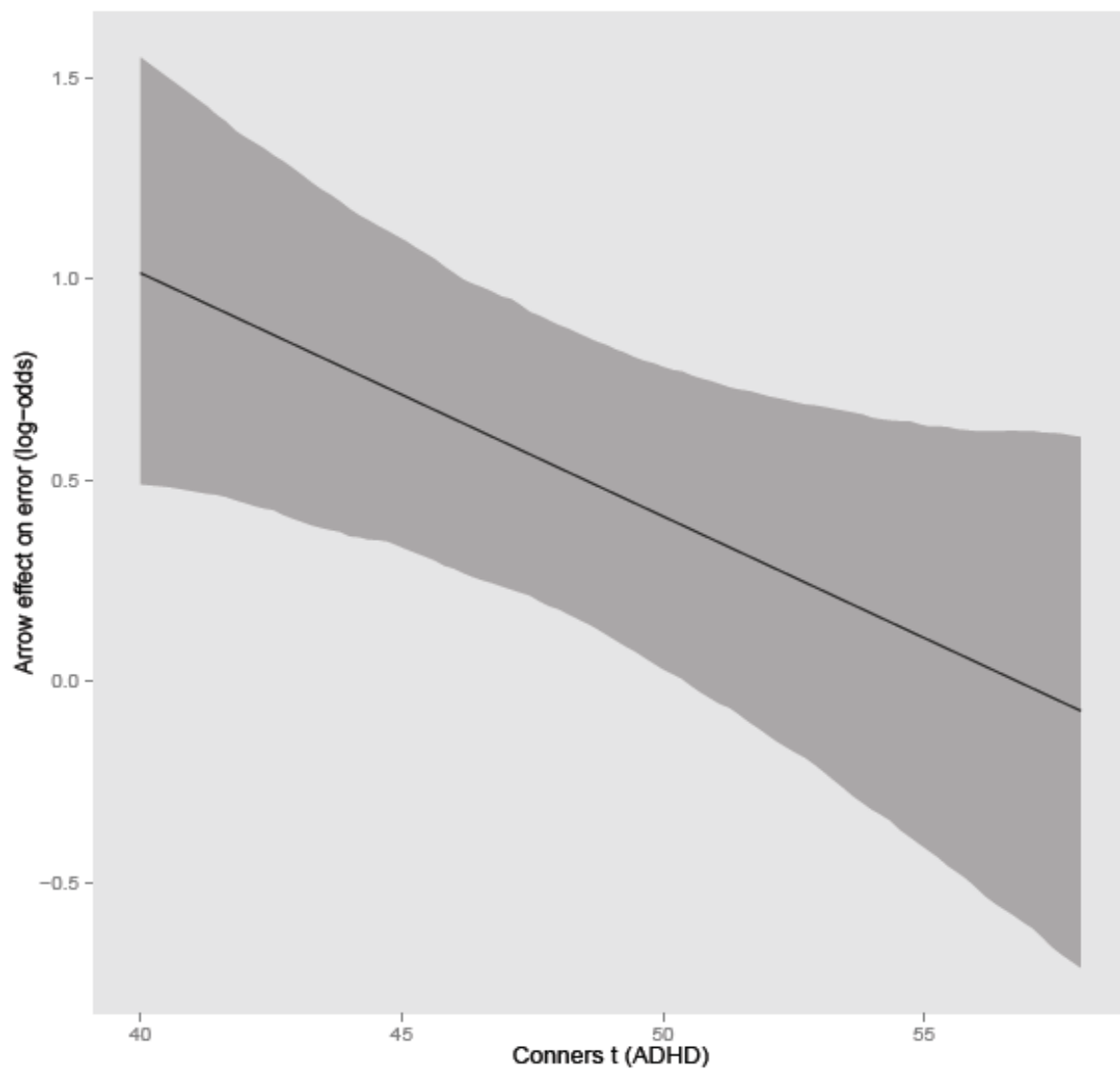


Figure 16. Orienting effects on error rates plotted by Conners ADHD scores and by difference scores for log odds of errors.