

THE ATTENTION NETWORK TEST (ANT): INDIVIDUAL DIFFERENCES
AND
COMPONENTS OF ATTENTION ACROSS THE LIFE SPAN

by

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ABSTRACT

Using orthogonal subtractions of performance in selected conditions the attentional network test (ANT) measures the efficacy of three isolable components of attention: alerting, orienting, and executive control. This dissertation evaluated: 1) the relationship between these attention networks and absentmindedness measured by the Cognitive Failures Questionnaire (CFQ) and 2) stability, isolability, robustness, and reliability of the two versions of the ANT (Fan et al., 2002 and Callejas et al., 2005) with young adults and older adults and of the child version of the ANT (Rueda et al., 2004) with young children when tested over 10 sessions. A greater degree of absentmindedness as measured with CFQ was associated with a greater alerting network score in RT and with a greater orienting network scores in error rate when the ANT-I was used. However, a greater degree of absentmindedness was associated with a smaller orienting network score in error rate when the ANT was used. These results suggest that the alerting and the orienting networks are related to absentmindedness. However, the orienting networks in the two ANTs were related to absentmindedness differently which supports the proposal (Klein, 2009) that there are fundamental differences between attention when controlled endogenously (ANT) as opposed to exogenously (ANT-I). For young adults and older adults, all network scores in RT remained robust even after nine previous sessions despite some practice effects especially in the executive network both with the ANT and the ANT-I. There was some evidence that the networks do not operate independently in all situations. As expected, reliability increased as more data are added. For young children, only the alerting network scores remained robust over time. Learning effects were observed only with the executive network. The reliability was poor even when more data were added. This made it difficult to assess the isolability of the network scores. The ANT and the ANT-I were associated to the CFQ scores in a limited way. The ANT and the ANT-I can be used for applications requiring repeated testing, but the child ANT may not be suitable for such purpose.

LIST OF ABBREVIATIONS AND SYMBOLS USED

ADHD	Attention Deficit Hyperactivity Disorder
ADHD-I or ADHD-IA	ADHD inattentive subtype
ADHD-C	Combined inattentive/hyperactive
ANOVA	Analysis of Variance
ANT	Attention Network Test
ANT-I	Attention Network Test – Interaction, or modified ANT
BIS	Behavioral Inhibition System
BPD	Borderline Personality Disorder\
CFQ	Cognitive Failures Questionnaire
Child ANT	Child version of the Attention Network Test
COMT	Catechol-O-methyltransferase
COPD	Chronic Obstructive Pulmonary Disease
CUD	Cocaine Use Disorders
fMRI	Functional magnetic resonance imaging
MCI	Mild Cognitive Impairment
MD	Major Depression
ms	millisecond
MS	Multiple Sclerosis
mTBI	Mild Traumatic Brain Injuries
PD	Parkinson’s Disease
PTSD	Posttraumatic Stress Disorder
RT	Reaction time
SART	Sustained Attention to Response Task
SES	Socioeconomic Status
SNAP	Synaptosomal-associated protein
SOA	Stimulus onset asynchrony
TEA	Test of Everyday Attention
TPH2 703 G/ T	Tryptophan hydroxylase 2
UFOV	Useful Field of View
WMC	Working Memory Capacity
22q11 DS	22q11 Deletion Syndrome

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CHAPTER 1: INTRODUCTION

This dissertation is comprised of manuscripts [published (Chapters 2-3) or submitted (Chapters 4-5)]. Some overlap in the topics covered across the chapters was inevitable in order to make each manuscript self-contained. Co-author for these manuscripts is Dr. Raymond Klein. I was responsible for researching, analyzing data, and writing the manuscripts. Dr. Klein gave me intellectual guidance and editorial advice.

Attention is not a unitary concept. Rather, attention includes multiple separate yet interacting components. Different researchers have divided up the components of attention in different ways. Regardless of how it is divided, the understanding and measurement of these components is interesting and important, particularly in the context of individual differences, development, cognitive deficits, and cognitive rehabilitation. Posner and Petersen (1990) compartmentalized attention into three components - alerting, orienting, and executive control. Fan, McCandliss, Sommer, Raz, and Posner (2002) developed a test to measure these three components.

The original Attention Network Test (ANT) was developed by Fan et al. (2002) to measure three attention networks: alerting, orienting, and executive control. The ANT is a combination of a Posner's cueing task (1980) and Eriksen's flanker task (1974). In Posner's cueing task, spatial attention is manipulated by a 'cue' which is followed by a target presented at the same location as the cue (cued) or at the different location as the cue (uncued). The cue may automatically or/and voluntarily capture attention. Performance is worse in uncued trials because attention, after being captured by the cue must be disengaged and reoriented to the target. Often efficiency of orienting is calculated as the difference between performance on cued and uncued trials. Interpreting the orienting scores needs a caution because large orienting scores can occur because of difficulties disengaging attention or because of increased effort to take advantage of cues, especially when they are informative (Fan & Posner, 2004). In Eriksen's flanker task, executive attention is measured by the effect of congruent versus incongruent flankers (noise) surrounding a target, whose location is typically known. To process the target

efficiently, the flankers should be ignored. To the extent that executive control fails and the flankers are processed, performance will be worse when the identity of the flankers are different from that of the target (incongruent) especially when spacing between these stimuli is close.

Alerting¹ involves maintaining mental sensitivity to stimuli in the environment, orienting involves selectively allocating attention to stimuli in the environment, and executive control involves monitoring events and resolving conflicts. On each trial in the ANT, different types of warning cue (i.e., center cue, double cue, spatial cue, or no cue) precede a central target arrow, pointing either left or right, that is often flanked by distracting arrows (congruent or incongruent). The task is to indicate the direction of the arrow in the middle. The alerting and orienting network scores are calculated as difference scores between two specific conditions in cue condition variable (double cue minus no cue condition for the alerting network, and center cue minus spatial cue conditions for the orienting network), and the executive network scores are calculated as difference scores between two specific conditions in target congruency variable (incongruent minus congruent conditions).

There is a child version of the ANT (child ANT) developed by Rueda et al. (2004). This is a child-friendly version. Instead of arrows, colorful fish are used as the stimuli. In addition, feedback (e.g., 'Woohoo' sound for correct responses) is given. Otherwise, the design of the child ANT is almost identical to the ANT. Later, the

¹ Alerting in the ANT and the ANT-I is like temporal endogenous attention because the SOA is fixed. But, alerting in both ANTs is also like exogenous temporal attention because the warning cue might automatically arouse a participant. The ANTs do not distinguish these two types of alerting (see Lawrence, Klein, & LoLordo, 2008 for a study distinguishing these two modes of temporal attention).

Attention Network Test – Interaction (ANT-I) was developed by Callejas, Lupianes, Funes, and Tudela (2005). Different from the ANT (and the child ANT), the ANT-I enables analyses of interactions among the network scores because the three networks are defined by different variables (auditory signal, visual cue, and target congruency for the alerting, orienting and executive networks, respectively).

Different areas of the brain have been found to be associated with these networks when corresponding attention tasks are performed (Figure 1.1). Alerting was found to associate with thalamic, frontal, and parietal areas (Coull, Frith, Frackowiak, & Grasby, 1996; Marrocco & Davidson, 1998; Posner & Petersen, 1990). Lesion studies suggest that those areas in the right hemisphere in particular have important contributions to alerting (Posner & Petersen, 1990; Robertson, Tegner, Tham, Lo, & Nimmosmith, I. 1995; Sturm & Willness, 2001). Fan, McCandliss, Fossella, Flombaum, and Posner (2005) confirmed activations in these areas as well as activations in the superior colliculus and the right temporal parietal junction using event-related functional magnetic resonance imaging (fMRI) when the participants were performing the ANT².

Interestingly, the frontal and parietal activities in the left hemisphere were stronger than those in the right. These patterns were interpreted by Fan et al. (2005) that the cue was used to temporally orient attention because the stimulus onset asynchrony (SOA) between the cue and the target was fixed. Orienting was found to be associated with activity in the superior parietal area, temporal parietal junction, and frontal eye fields (Corbetta & Shulman, 2002). Lesion studies suggest that the right parietal area, especially

² Their design was 3 (cue condition: no cue, center cue, and spatial cue) x 2 (target congruency); the double cue condition in the original ANT (Fan et al., 2002) was not included in cue condition.

the temporal parietal junction, has important contributions in left visuo-spatial neglect (e.g., Vallar, 2001). Fan et al. (2005) confirmed activations in these areas, except activation in the right temporal parietal junction, with the ANT. Executive control is associated with anterior cingulate and prefrontal area (Bush, Luu, & Posner, 2000; MacDonald, Cohen, Stenger, & Carter, 2000). Fan et al. (2005) confirmed activations in these areas as well as activations in fusiform gyrus with the ANT. It has been suggested that the prefrontal areas are associated with conflict resolution during response preparation while the anterior cingulate areas are associated with conflict monitoring during response execution (MacDonald et al., 2000). Interestingly, these areas associated with executive control did not overlap with areas activated by alerting or orienting (Fan et al., 2005).

The ANTs are useful tools for measuring the three attention networks within a single 20-minute session. They are simple and have been used to study wide range of populations: primate (Beran, Washburn, & Kleinman, 2003), young children (e.g., Rueda et al., 2004), young adults (e.g., Callejas et al., 2005; Fan et al., 2002), older adults (e.g., Fernandez-Duque & Black, 2006), and clinical patients (e.g., Posner et al., 2002). Among these populations, the ANTs have been used to study associations between a number of pathologies and the different components of attention (Table 1.1³) and to study effects of a wide range of variables on these components or associations between these (Table 1.2³). Some disorders and variables are associated with the same network (e.g., differences in the executive network may differentiate individuals with attention deficit hyperactivity

³ Studies that used modified versions of these tests are excluded from the table.

disorder (ADHD), borderline personality disorder (BPD), or schizophrenia from individuals without these disorders). At the same time, some disorders and variables can be associated with more than two networks (e.g., both the alerting and the executive networks may differentiate individuals with ADHD from individuals without ADHD). Although these patterns (Tables 1.1 and 1.2) make it difficult for the ANTs to be used as diagnostic tools for different disorders (Rothbart & Posner, 2006), the tests are useful for understanding how different disorders and variables affect the different networks of attention. Importantly, performance patterns from these tests might be used to identify potential treatments to remediate an impaired network (Rothbart & Posner, 2006).

Although the ANTs are used frequently and widely, the literature examining individual differences in the attention networks measured by them is limited. It has been found that the executive network scores measured with the ANT were related to working memory capacity measured with Operation Span (OSPAN: Turner & Engle, 1989) (Redick & Engle, 2006), but were not related to absentmindedness or self-reported cognitive failures measured by the Cognitive Failures Questionnaire (CFQ: Broadbent, Cooper, Fitzgerald, & Parkers, 1982, see Appendix A) (Reinholdt-Dunne, Mogg, & Bradley, 2009). In Chapter 2, relationships between CFQ scores and the attention networks measured by the two versions of the ANT (ANT and ANT-I) will be examined with more power (published in the *Journal of Individual Differences*: Ishigami & Klein, 2009a).

As an assessment tool, one possible use of the ANTs is repeated testing (e.g., longitudinal studies or studies of effects of training/rehabilitation). In fact, several studies

repeatedly administered the ANT or the child ANT to examine the effects of some treatment on the attention networks (e. g., Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005; Tang et al., 2007). For example, Tang et al. administered the ANT before and after meditation training to university students to examine effects of the training on the alerting, orienting, and executive functions (see also Jha, Krompinger, & Baime, 2007). However, the stability, robustness⁴, and reliability of the network scores over multiple sessions are unknown. In addition, the stability, robustness, and reliability of the network scores when people from different age groups are tested is unknown. If performance of the test is not stable over time, a control group without a treatment would be needed. If performance of the test is not robust, then the test is not always measuring what it is supposed to measure. If performance of the test is not reliable, a caution would be needed to compare performance measured at different times in the same participant.

Further, differences in network scores between the ANT and the ANT-I when administered repeatedly is unknown. To address these issues and to replicate isolability among the networks (Fan et al., 2002; Callejas et al., 2005; Rueda et al., 2004), three experiments were conducted and reported in Chapters 3 - 5. In Chapter 3, the ANT and the ANT-I were administered to young adults over ten sessions and the network scores were examined (published in the *Journal of Neuroscience Methods*: Ishigami & Klein, 2010). In Chapter 4, the ANT and the ANT-I were administered to older adults over ten sessions (submitted for publication to the *Frontiers in Aging and Neuroscience*). In Chapter 5, the child ANT was administered to young children over ten sessions

⁴ 'Robust' means that network scores measured with the ANTs are significantly different from zero.

(submitted for publication to the Journal of Attention Disorders). Finally, a summary and a conclusion of the results from Chapter 2 – 5 was presented in Chapter 6.

Table 1.1

Disorders that have been studied using the ANT, the ANT-I, and the child ANT. Studies that used modified versions of these tests are excluded from this table. Numbers under each network column indicate corresponding studies that found differences between groups (either disordered versus control group or versus another disordered group), or correlations between the severity of disorders and the networks.

ANT

Disorder	Alerting	Orienting	Executive
ADHD (children) ¹	1		1
ADHD (adolescents) ²			2
ADHD-I vs ADHD-C ³	3	3	3
ADHD vs BPD ⁴			4
ADHD + BPD (women) ⁵	-	-	5**
BPD ^{6*7}		6	7
Concussion ⁸		8	8
COPD ⁹	9	9	
CUD ¹⁰			10
Deafness ¹¹			11*/**
Dyslexia ¹²		12	
MCI ¹³			
MD vs Manic state vs Depressed state ^{14*}			
MS ¹⁵	15		
PD ¹⁶	16	16	16
PTSD ¹⁷			19
Schizophrenia ^{18,19, 20,21,22,23}	23 (ratio)	21 (ratio)	18,20,21,22
TBI ²⁴		24	

ANT-I

Disorder	Alerting	Orienting	Executive
Trait anxiety ²⁵			25
State anxiety ²⁵	25	25	

Child ANT

Disorder	Alerting	Orienting	Executive
22q11 DS ^{26,27}			26,27
ADHD ^{28,29,30}			30
ADHD-IA vs -C ²⁹	29		
Corrective cardiac surgery ³¹			31
BPD precursors ³²			32
Dyslexia ³³			33
Preterm ³⁴			34

- * Executive network = Incongruent - neutral
- ** There was a trend or marginal significance
- Network scores were not examined

- ¹ Johnson et al. (2008)
- ² Loo et al. (2007)
- ³ Oberlin et al. (2005)
- ⁴ Lampe et al. (2007)
- ⁵ Rusch et al. (2007)
- ⁶ Fertuck et al. (2005)
- ⁷ Posner et al. (2002)
- ⁸ van Donkelaar et al. (2005)
- ⁹ Klein et al. (2010)
- ¹⁰ Woicik et al. (2009)
- ¹¹ Dye et al. (2007)
- ¹² Buchholtz & Davies (2008)
- ¹³ Lv et al. (2010)
- ¹⁴ Gruber et al. (2007)
- ¹⁵ Urbanek et al. (2010)
- ¹⁶ Lou (2009)
- ¹⁷ Leskin & White (2007)
- ¹⁸ Opgen-Rhein et al. (2008), examined only the executive network
- ¹⁹ AhnAllen et al. (2008)
- ²⁰ Gooding et al. (2006)
- ²¹ Wang et al. (2005)
- ²² Urbanek et al. (2009)
- ²³ Nestor et al. (2007)
- ²⁴ Catena et al. (2009)
- ²⁵ Askenazi & Henik (2010)
- ²⁶ Sobin et al. (2005)
- ²⁷ Sobin et al. (2004)
- ²⁸ Adólfsdóttir et al. (2008)
- ²⁹ Booth et al. (2007)
- ³⁰ Konrad et al. (2010)
- ³¹ Hovels-Gurich et al. (2007)
- ³² Rogosch & Cicchetti (2005)
- ³³ Bednarek et al. (2004)
- ³⁴ Pizzo et al. (2010)

Table 1.2

Variables whose effects on the ANT, the ANT-I, and the child ANT have been studied. Studies that used modified versions of these tests are excluded from this table. Numbers under each network column indicate corresponding studies that found effects of the functions on the ANTs or correlations between effects and the networks.

<i>ANT</i>			
Function	Alerting	Orienting	Executive
Age ¹	1		
Anxiety (trait anxiety) ²			
Bilingualism ³	3		3
Chronotype ⁴			
Cognitive control/capacity (WMC) ⁵			5
Cognitive control/capacity (WCST) (BPD) ⁶			6
Cognitive control/capacity (CFQ) ²			
Cognitive control/capacity (mother-reported (not self-reported) effortful control) ⁷	-	-	7
Emotional modulation ^{8, 9}			8, 9
Fearful sensitivity (BIS) ⁹			
Genotype (COMT Val ^{108/158} Met) ¹⁰	-	-	10
Genotype (COMT Val ¹⁵⁸ Met) ¹¹			
Genotype (TPH2-703 G/T) ¹¹			11
Genotype (SNAP25) ¹²	-	-	12
Genotype (MAOA) ¹³	-	-	13**
Genotype (DRD4) ¹³	-	-	13
Hypnotizability ¹⁴	14		

Function	Alerting	Orienting	Executive
Meditation experience ¹⁵			15
Mood change ¹⁶			
Sex ¹⁷			17
Substance (caffeine) ¹⁸	18	18**	18, 19
Substance (nicotine) ^{19, 20}			
Switch cost (task performance) ²¹	21		
Switch probability (task choice) ²¹			21
Sensory gating (ERP) ²²	22		22
Time-of-day ⁴			4
Treatment (interaction with nature) ²³			23
Treatment (mindfulness/meditation) ^{15, 24}	15	15	24
UFOV ²⁵			25

ANT-I

Functions	Alerting	Orienting	Executive
Anxiety (trait anxiety) ²⁶			26
Anxiety (state anxiety) ²⁶	26	26	

Child ANT

Functions	Alerting	Orienting	Executive
Age ^{27, 28}	27	27	27,28
Bilingualism ²⁹	-	-	
Emotional modulation ³⁰		30	
Emotional regulation (mother reported) ³¹ -		-	31
Intelligence (fluid) ³²	-	-	32
Intelligence (crystallized) ³²			
Maltreatment ³³			
SES ³³	33		33
Speed of TV editing ³⁴	34	34	
Training (executive control) ³⁵	-	-	
Video gaming ³⁶		36	36

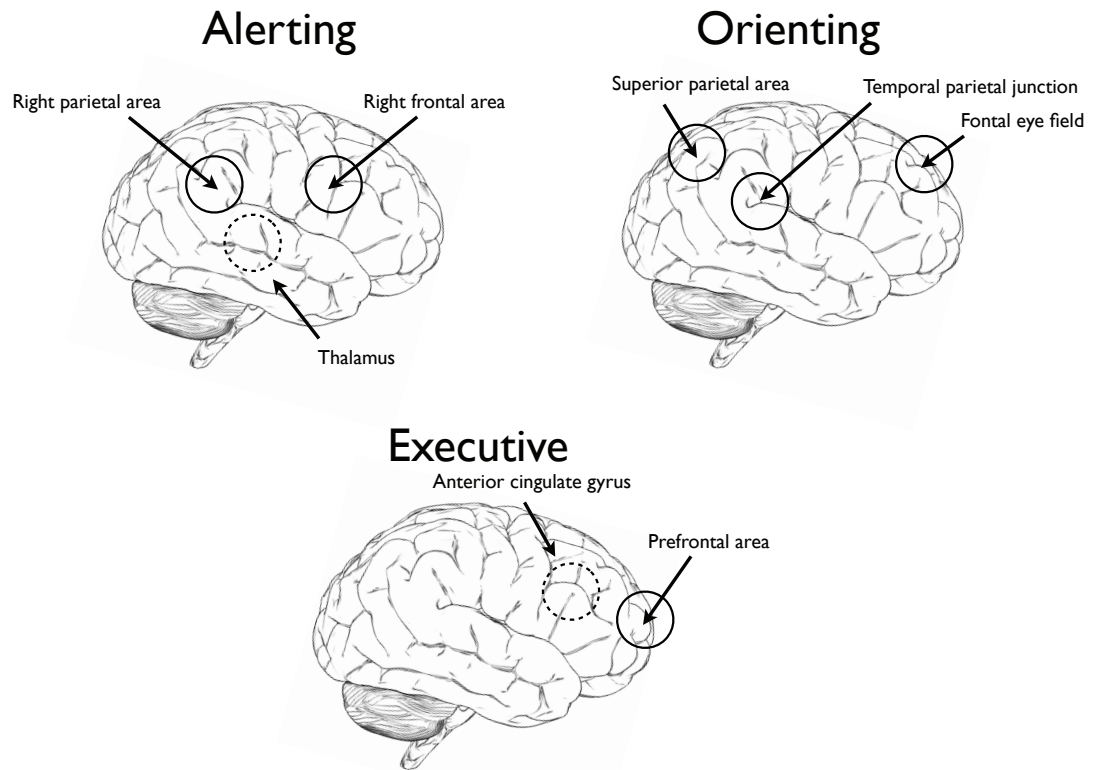
* Executive network = Incongruent - neutral

** *There was a trend or marginal significance*

- *Network scores were not examined*

- ¹ Jennings et al. (2007)
- ² Reinholdt-Dunne et al. (2009)
- ³ Costa et al. (2008)
- ⁴ Matchock & Mordkoff (2009)
- ⁵ Redick & Engle (2006)
- ⁶ Fertuck et al. (2005)
- ⁷ Ellis et al. (2004)
- ⁸ Finucane & Power (2010)
- ⁹ Dennis & Chen (2007b)
- ¹⁰ Opgen-Rhein et al. (2008), candidate gene for schizophrenia
- ¹¹ Reuter et al. (2007)
- ¹² Fossella et al. (2003)
- ¹³ Fan et al. (2003)
- ¹⁴ Castellani et al. (2007)
- ¹⁵ Jha et al. (2007)
- ¹⁶ Isaacowitz et al. (2009)
- ¹⁷ Neuhaus et al. (2009)
- ¹⁸ Brunye et al. (2010)
- ¹⁹ Blank et al. (2007)
- ²⁰ Kleykamp et al. (2005)
- ²¹ Arrington & Yates (2009)
- ²² Wan et al. (2008)
- ²³ Berman et al. (2008)
- ²⁴ Tang et al. (2007)
- ²⁵ Weaver et al. (2009)
- ²⁶ Pacheco-Unguetti et al. (2010)
- ²⁷ Mezzacappa (2004)
- ²⁸ Rueda et al. (2004)
- ²⁹ Carlson & Meltzoff (2008)
- ³⁰ Dennis et al. (2007a)
- ³¹ Simonds et al. (2007)
- ³² Tillman et al. (2009)
- ³³ Rogosch & Cicchetti (2005)
- ³⁴ Cooper et al. (2009)
- ³⁵ Rueda et al. (2005)
- ³⁶ Dye et al. (2009)

Figure 1.1
Areas of the brain associated with each attention network.



CHAPTER 2:
ARE INDIVIDUAL DIFFERENCES IN ABSENTMINDEDNESS CORRELATED
WITH INDIVIDUAL DIFFERENCES IN ATTENTION?

The manuscript based on this study is presented below. Co-author for this manuscript is Dr. Raymond Klein.

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Abstract

We administered the Cognitive Failures Questionnaire (CFQ) and one of two versions of the Attention Network Test (ANT) to 200 participants. Orthogonal subtraction scores based on performance (reaction time and error rate) from selected conditions of the ANT provided measures of the efficacy of three attention components: alerting, orienting, and executive control while the total CFQ score provided a global measure of absentmindedness. Executive control was not associated with the CFQ in either experiment. When alertness was generated by a warning tone, greater alerting effects in reaction time were associated with higher CFQ scores (greater absentmindedness). The orienting effects in error rate obtained from the two versions of the ANT varied with absentmindedness in opposite directions suggesting that these two tests tap different aspects of orienting.

Introduction

Absentmindedness is a state of being inattentive to ongoing activities and losing track of their current aims. Because of absentmindedness, salient but irrelevant stimuli may distract intended thought or action (Manly, Robertson, Galloway, & Hawkins, 1999). Consequences can be minor but annoying everyday mistakes at home, school, or work. Consequences can also be serious and deadly when situations are demanding, such as driving a car or piloting an aircraft (Reason, 1979). Although it is intuitively appealing to consider that individual differences in basic attentional mechanisms might underlie everyday mistakes associated with absentmindedness, results from studies examining the relationship between everyday mistakes and laboratory attention tasks have so far been inconsistent (see below). This is the relationship the current study will reexamine using the Cognitive Failures Questionnaire (CFQ) (Broadbent, Cooper, Fitzgerald, & Parkers, 1982) and the Attention Network Tests (ANT) (Callejas, Lupianez, Funes, & Tudela, 2005; Fan, McCandliss, Sommer, Raz, & Posner, 2002).

The CFQ is a 25-item instrument on a five-point scale developed by Broadbent et al. (1982) to assess the frequency of everyday slips and errors in the past six months. Typically, the sum of the scores is calculated and higher scores indicate greater 'absentmindedness.' Participants are simply asked to indicate the frequency of particular slips and errors. CFQ scores are only weakly related to standard personality and unrelated to intelligence scales in general (Broadbent et al., 1982). Rather, CFQ scores are related to stress (Broadbent et al., 1982; van der Linden, Keijsers, Eling, & van Schaijk, 2005) proneness to boredom and daytime sleepiness (Wallace, Vodanvoich, & Restino, 2003),

failure in saving everyday computing work (Jones & Martin, 2003), the number of citations for traffic accidents, and the number of hospitalizations following injuries (Larson, Alderton, Neideffer, & Underhill, 1997).

While interesting, such studies are not informative about the possible attentional foundation of cognitive failures – which components of attention are associated with absentmindedness? Posner and Petersen (1990) proposed three components of attention (alerting, orienting, and executive control), each mediated by a different neural network that performs different but interrelated functions. These networks are defined in anatomical and functional terms, by finding correspondence between lesions to and activation of regions in the brain and performance in attention tasks that measure different functions of attention. Alerting involves a change in mental state as well as some changes in physiological state. Right hemisphere and thalamic areas are involved in alerting (e.g., Coull, Frith, Frackowiak, & Grasby, 1996; Sturm & Willmes, 2001). There are two types of alerting: tonic and phasic. Tonic alertness is a state of general wakefulness or vigilance and refers to a sustained activation of attention during a period of time. Phasic alertness is the ability to increase response readiness following a temporary activation of attention by a signal that only provides temporal information regarding target presentations (Callejas et al., 2005; Posner, 1978; Sturm & Willmes, 2001). In addition to the right hemisphere and the thalamic set of areas, left frontal and parietal areas have been associated with phasic alertness (Sturm & Willmes, 2001). Orienting involves turning attention to some source of signals in space (Posner, 1978). Areas of the parietal lobe, the midbrain, and the thalamus have been associated with this

function (Posner & Raichle, 1994). Executive control involves conflict resolution, control over decision-making, error detection, and habitual response inhibition (Norman & Shallice, 1986). The anterior cingulate cortex and the lateral prefrontal cortex have been associated with this function (e.g., Bush, Luu, & Posner, 2000; Casey et al., 2000).

To determine the possible attentional foundation of cognitive failures, studies seeking to link laboratory measures of attention and CFQ scores were examined (see Table 2.1) and will be discussed in relation to attention networks identified by Posner and Peterson (1990). Because of its name, the Sustained Attention to Response Task (SART, Robertson, Manly, Andrade, Baddeley, & Yiend, 1997), has been assumed by some to tap “sustained attention.” However, we believe that performance on the SART, in fact, reflects executive control (see also Chan, Shum, Touloupoulou, & Chen, 2008; Helton, 2009). Robertson et al.’s multiple regression analyses with the SART as an dependent variable show that tests that have dual task components (i.e., Lottery subtest of the Test of Everyday Attention (TEA) and Telephone Search with Counting Subtest of the TEA) explained more variance on the SART than did tasks that have task-switching components (i.e., Wisconsin Card Sorting Test, Visual Elevator Subtest of the TEA).

In the SART, participants have to respond with a key press whenever frequent digits are detected while withholding responses to a particular infrequent digit (0.11 probability)⁵. The results from studies examining the relationship between performance in the SART and CFQ scores are mixed. Robertson et al. (1997) reported that participants with higher CFQ scores made more false alarms (i.e., responding to the infrequent digit)

⁵ Unfortunately, Robertson et al. (1997) referred to these not-to-be-responded-to items as targets. We believe this use of the term is confusing or even inappropriate.

(see also Farrin, Hull, Unwin, Wykes, & David, 2003; Manly et al., 1999) while Wallace, Kass, and Stanny (2001) reported that neither false alarms nor misses were linked to CFQ scores. Manly et al. (1999) extended this study by manipulating the probability of the infrequent digit (low vs. high) in the SART. There was no difference in false alarms between the high and low CFQ groups when the probability of the infrequent digit was high (0.5 probability), but there was a difference as in Robertson's study when the probability of the infrequent digit was low (0.11 probability). It appears that absentminded individuals have difficulty withholding responses to infrequent non-targets, a finding that could reflect an executive function failure called 'goal-neglect' (cf Duncan, 1995).

The relationship between orienting and CFQ scores was studied by Broadbent et al. (1986) using a variation of a cueing and flanker task. Efficiency of orienting or what Broadbent referred to as "search" was studied by comparing performance when the target location was known versus unknown. They found a weak but significant negative relationship between this measure and CFQ scores. Although the authors described this correlation as reflecting that absentmindedness was "associated with relatively poorer performance when target location is known in advance" there are two rather different interpretations. Participants with high CFQ scores may benefit less from known target locations. Alternatively, participants with the high CFQ scores suffer less from unknown locations. Unfortunately, Broadbent et al. did not present the results in a way that we can distinguish between these possibilities.

Executive control in the CFQ and attention literature has been studied using a

variety of tasks, tapping different aspects of executive control. Accordingly, perhaps, the results in the studies examining the relationship between executive control and CFQ scores are considerably mixed (see Table 2.1). Tasks performed in these studies vary in terms of number and feature of distractors (e.g., word or letter), knowledge of target location (known or unknown), or participants (in number and age). Even within the same task, results are mixed. For example, one of the tasks to measure conflict resolution is a flanker task. In a flanker task, the participants have to respond to a target while ignoring irrelevant flanking distractors (Eriksen & Eriksen, 1974). Tipper and Baylis (1987) reported that the high CFQ group took longer to respond to a target word (e.g., “dog”) in the presence of semantically unrelated distracting word (e.g., “music”) presented either above or below the target than the low CFQ group (see also Kramer, Humphrey, Larish, Logan, & Strayer, 1994). In addition, Forster and Lavie (2007) reported that the high CFQ group took longer to identify a target letter while ignoring distracting letters than the low CFQ group when perceptual load is low. On the other hand, Broadbent et al. (1986) reported a null relationship between the measure of conflict resolution and CFQ scores when the participants had to respond to a target letter (e.g., ‘A’) while ignoring distractor letters (e.g., ‘B’) presented to the left and the right of the target. One possibly important difference between these studies is that in Tipper and Baylis as well as in Forster and Lavie the locations of the target and/or distractors were unknown while in Broadbent's task target and distractor locations were known in advance (see also Kramer et al., 1994). Moreover, because reading a word is a rather automatic behavior (e.g., Stroop, 1935), ignoring a distracting word might require greater effortful control than ignoring a

distracting letter making the Tipper and Baylis task perhaps more sensitive.

Thus, the results from the previous studies⁶ are mixed regarding whether attention measured in laboratories is linked to CFQ scores. One possible contributor to the mixed results could be that the tasks used, their levels of difficulty, functions of attention they measured, and power differed across the studies. Here we use two versions of the recently developed ANT (Fan et al, 2002; Callejas et al., 2005), which measure three isolable attention networks (alerting, orienting, and executive control) in a single task, to explore the possibility that these neural based networks of attention might be linked to absentmindedness as measured by the CFQ.

The original ANT (we will refer to it as simply ‘ANT’) was developed by Fan et al. (2002) to measure three isolable attention networks: alerting, orienting, and executive control. The ANT is a simple, yet carefully designed, test of performance in which specific subtraction scores are used to measure the efficiency of three different attention networks (Klein, 2003). On each trial, different types of warning cue precede a central target arrow, pointing either left or right, that is often flanked by distracting arrows. The participants’ task is to indicate the direction of the target arrow as quickly and accurately as possible. The efficiency of the alerting and orienting networks are measured comparing performance in the different types of cuing condition (center, double, spatial, and no cues). The efficiency of the executive network is measured comparing performance in the different types of target congruency condition (congruent and

⁶ Meiran, Israeli, Levi and Grafi (1994) explored the relation between cognitive failures and performance in three experiments. Although there were significant correlations between CFQ scores and aspects of performance in two of these experiments, it is difficult today to confidently link these aspects to generally accepted components of attention.

incongruent). Fan et al. (2002) demonstrated that the ANT was a reliable measure of each network (alerting, orienting and executive control). In addition, they suggested that each network was independent of the others by showing no significant correlations among the network scores.

However, there are two limitations in the test developed by Fan et al. (2002). First, the alerting and the orienting networks are both defined by the cue condition. This means that we cannot know whether the alerting and the orienting networks interact. Relatedly, we cannot separate a potential interaction between the alerting and orienting networks from the significant interaction⁷ between cue condition and target congruency, which Fan et al. (2002) reported. Second, their peripheral cue (spatial cue condition), which is one of two cue conditions that define the orienting network, has a 100% validity in terms of the location of the target. Thus, when measuring the orienting effect, which is defined by the spatial cue and the center cue, exogenous and endogenous components are confounded (Klein, 2004).

Callejas et al. (2005) developed an alternative version of the ANT (we will refer to it as the modified ANT) to overcome these limitations. As with the ANT, the orienting and executive networks are defined by the visual cue (valid and invalid) and target congruency (congruent and incongruent), respectively. However, the alerting network is defined by auditory signals (tone and no tone). The separation of the alerting (auditory) from the orienting (visual) cues permits the researcher using this task to explore performance as a joint function of orienting (valid vs. invalid) and alerting (tone vs. no

⁷ This interaction suggests some lack of independence among the networks. It is partly for this reason that we adopt the weaker term (from Posner, 1978) “isolable.”

tone). In addition, auditory signals have been reported to capture attention more automatically than visual signals (Posner, Nissen & Klein, 1976). Thus, this design permits the researcher to examine the interaction among the networks with confidence. In addition, uninformative peripheral cues were used to define the orienting network in the modified ANT. The use of uninformative peripheral cues allows the researcher to measure the pure effect of exogenous orienting without contamination by the endogenous component. Callejas et al. reported statistical interactions among all the networks, and concluded that: 1) The executive network is inhibited by the alerting network (see also Posner, 1994): 2) The executive network is facilitated by the orienting network (see also Funes, Lupianez, & Milliken, 2007): and 3) The orienting network is facilitated by the alerting network (see also Sturm, Thimm, Kust, Karbe, & Fink, 2006; Thimm, Fink, Kust, Karbe, & Sturm, 2006). Thus, Callejas et al. concluded that the attention networks measured by the ANT do not operate independently (see also Cohen et al., 1988; Funes et al., 2007; Posner, 1994, for further evidence of the dependence among the networks).

The current study measures three attention networks (alerting, orienting, and executive control) via the ANT (Fan et al. 2002) in Experiment 1 and via the modified ANT (Callejas et al. 2005) in Experiment 2 and the resulting network scores were examined in the relation to absentmindedness measured by the CFQ. As far as we know, this is the first attempt to examine the relationship between three attention networks and absentmindedness using either version of the ANT. Moreover, phasic alertness has, to our knowledge, not been examined with the CFQ. Finally, more participants were run in the current study than most of the previous studies, thereby giving us more power to detect

the relationship between attention and absentmindedness. We have two objectives in our study: 1) to examine whether individual differences in everyday errors or absentmindedness, measured in the CFQ, would be correlated with the attentional functions measured by the ANT and 2) to reexamine the relationship between the three attention networks while comparing the findings from the two versions of the ANT used by Fan et al. (2002) and Callejas et al. (2005).

What relations might we expect to find? To the extent that participants are absentminded: 1) They may react more strongly to salient warning stimuli; in this case, high CFQ scores would be associated with greater alerting effects (i.e., positive correlation) (Hypothesis 1); 2) They may not be able to take advantage of an informative spatial cue (Broadbent et al., 1986), but they cannot help paying attention to uninformative peripheral cues; in this case high CFQ scores would be associated with the smaller orienting effects in Experiment 1 and greater orienting effects in Experiment 2 (Hypothesis 2); and 3) They may become distracted by irrelevant information in which case high CFQ scores would be associated with the higher executive effects (i.e., positive correlation) (Hypothesis 3). We do not specifically endorse any one of these hypotheses and it should be noted that they are not mutually exclusive; they could, in fact, all be true. Rather, our study seeks to determine whether one or more of these hypothetical relations will be revealed in our relatively well-powered study.

Experiment 1: ANT (Fan et al., 2002) and CFQ

The ANT (Fan et al., 2002) was used in Experiment 1 to measure three isolable attention networks (alerting, orienting, and executive control) and to examine their

relationship with the CFQ (Broadbent et al., 1982). In the ANT, the alerting and the orienting networks are defined by the cue condition (center, double, spatial, and no cues). The alerting network is calculated by subtracting performance of the double cue condition from performance of the no cue conditions. The orienting network is calculated by subtracting performance of the spatial cue condition from performance of the center cue condition. The executive network is defined by the target congruency condition (congruent and incongruent). The executive network is calculated by subtracting performance of the congruent condition from performance of the incongruent condition.

Method

Participants

One hundred students at Dalhousie University (65 females and 35 males) participated as a part of psychology class laboratory, for extra class credit or for money. All participants had normal or corrected-to-normal vision.

Apparatus and Materials

The Cognitive Failures Questionnaire (CFQ). The CFQ is a 25-item self-report inventory (e.g., Do you find you forget appointments?; the whole set of questions can be seen in Broadbent et al., 1982) developed by Broadbent et al. to assess the frequency of everyday slips and errors over the past 6 months. All questions were worded in the same direction. Participants were asked to indicate, on a 5-point scale (i.e., 0 = never, 4 = always), how often they committed that particular error. Total scores could range from 0 to 100, with higher scores indicating a higher level of absentmindedness.

Attention Network Test (ANT). We used the program (Java) written by researchers at the Sackler Institute for Developmental Psychobiology (http://sacklerinstitute.org/cornell/assays_and_tools/). One 14-inch iMac and 16-inch eMacs controlled stimulus presentation and response collection. Responses were made via two arrow keys (leftward and rightward) on a keyboard that was located in front of the participants. Stimuli were a fixation cross ($\sim 0.35^\circ$ visual angle), asterisk(s) ($\sim 0.35^\circ$ visual angle), and arrow(s) ($\sim 0.60^\circ$ visual angle in length, with $\sim 0.05^\circ$ visual angle distance between arrows) pointing either leftward or rightward (Figure 2.1.1). The target array (one central arrow and four flankers) was $\sim 3.2^\circ$ visual angle long. All of them were black presented on a light gray background.

Procedure and Design

CFQ. All participants completed the CFQ questionnaire before they performed the ANT (some when they signed themselves up for the subject pool; others on the same day that they performed the ANT).

ANT. The participants were tested in a dimly lit testing room (for iMac users) or an ordinarily lit psychology computer room (for eMac users). No restrictions were placed on the participants' movements and the monitor was located approximately 50-60 cm from the participants' eyes. The fixation cross was presented for 400-1600 ms in the center of the screen at the beginning of the experiment and remained until the end of a block. Then, the cue was presented for 100 ms. There were four types of cue: center, double, spatial, and no cue (Figure 2.1.1). In the center cue condition, a cue was presented in the center overlapping with the fixation cross. In the double cue condition, two cues were presented

above and below the fixation cross at the same time. In these conditions, the cues only gave temporal information that the target would be presented shortly. In the spatial cue condition, a cue was presented either above or below the fixation cross. In this condition, the cue gave both the temporal information and spatial information regarding the target location with 100% validity. In the no cue condition, no cue was presented. After 400 ms from the onset of the cue, the target array was presented until the participant responded, but for no longer than 1700 ms. There were three types of target array: congruent, incongruent, and neutral (Figure 2.1.1). In the congruent condition, the directions of the target arrow and the flanking arrows were the same. In the incongruent condition, the directions of the target arrow and the flanking arrows were different. In the neutral condition, the target arrow appeared by itself without the flanking arrows. The participants' task was to identify the direction of the target arrow, pressing the left arrow key on the keyboard when the target arrow pointed left and the right arrow key when the target arrow pointed right. After participants made a response, the target and the flankers disappeared immediately, followed by the second fixation period (3500 ms minus the first fixation period minus RT). The duration of each trial was 4000 ms.

The experiment contained four blocks. A practice block (24 trials) was followed by three experimental blocks (96 trials/block). Each cue condition was orthogonally crossed with three target congruency conditions in the experimental blocks. The 12 possible combinations of cue condition and target congruency were pseudo-randomly presented so that there were eight trials for each combination in an experimental block.

Participants were instructed to maintain fixation at the fixation cross all the time,

to identify the direction of the target (central) arrow and that quick and accurate responses would be important. Feedback following errors was given visually only in the practice block. The experiment lasted about 30 minutes.

Results And Discussion

Absentmindedness – CFQ

The total CFQ scores from 95 participants were available and analyzed (63 females and 32 males). The mean score for the CFQ was 42.7 ($SD = 11.7$). The distribution of CFQ scores in our sample is shown in Figure 2.2.

Attention - ANT

The data from four participants were excluded because their error rate (in this report the proportion of incorrect responses) in the ANT was too high (more than 2.5 standard deviation away from the mean) for us to put any faith in their reaction times, resulting in analyzing the data of 96 participants (63 females and 33 males, age range 17 – 37, mean age 21). For each participant, error rate and mean correct RT after eliminating extreme values (less than 200 ms and more than 1200 ms: 0.6% of the total) were computed and subjected to analyses. Table 2.2 and Figure 2.3 summarizes mean correct RT and error rate.

The mean correct RT and the error rate were submitted to ANOVAs with cue condition (center, double, spatial, and no cues) and target congruency (neutral, congruent, and incongruent) as repeated-measures factors. For RT, the main effects of cue condition, $F(3, 285) = 452.12$, $MSe = 647$, $p < .0001$, and target congruency, $F(2, 190) = 1116.0$, $MSe = 2369$, $p < .0001$, were significant. The interaction between cue condition and

target congruency was significant, $F(6, 570) = 22.936$, $MSe = 436$, $p < .0001$ (Figure 2.3), suggesting some lack of independence among the networks. The interaction precisely replicates the one reported by Fan et al. (2002) in which the negative impact of incongruent distractors was amplified when participants were alerted by non-spatial cues. For error rate, the main effects of cue condition, $F(3, 285) = 10.985$, $MSe = .00167$, $p < .0001$, and target congruency, $F(2, 190) = 95.269$, $MSe = .00646$, $p < .0001$, were significant. The interaction between cue condition and target congruency was significant, $F(6, 570) = 10.749$, $MSe = .0015$, $p < .0001$, suggesting some lack of independence among the networks. It can be seen in Figure 2.3 that the interaction was similar to and reinforces that seen in RT; the negative impact of distractors was greater in the presence of non-spatial cues.

Attention Network Scores

Table 2.3 summarizes attention network scores based on RT and error rate. One sample t -tests show that all the network scores were significantly different from zero in RT, $ps < .0001$, and in error rate, $ps < .01$. Thus, these results confirm that the ANT provides a usable index of each network both in RT and error rate. It is also worth noting that the significant benefits of the alerting double cue in RT are accompanied by significant costs in error rate (Figure 2.3). This speed-accuracy tradeoff is consistent with Posner's suggestion that phasic alertness speeds the time when information accumulating about a signal is used to generate a response without affecting the quality of the accumulating information (Posner, Klein, Summers & Buggie, 1973; Posner, 1975 & 1978).

Correlations Among the Networks

Table 2.4 shows the correlations among the alerting, orienting, and executive networks. There were no significant correlations in the analysis of the RT network scores. In the analysis of the error rate network scores, the alerting and the executive networks were negatively correlated (Figure 2.4) and the orienting and the executive networks were positively correlated (Figure 2.4); participants with greater congruency effects showed smaller alerting effects and greater orienting effects. The correlation between the alerting and orienting networks was not significant.

ANT and CFQ

Correlations between each network in the ANT and CFQ scores were examined⁸ (Table 2.5). None of the networks assessed via RT were correlated with the CFQ scores, whereas when assessed using accuracies, orienting and CFQ scores were negatively correlated (Figure 2.5.1); participants with higher CFQ scores (i.e., more absentminded) showed smaller orienting effects. This pattern supports our prediction (Hypothesis 2). To examine this correlation between orienting and CFQ scores further a median split was used to generate two groups, with high and low CFQ scores, and the mean orienting scores of the two groups were compared. It can be seen in Figure 2.6.1 that the mean orienting score of the high CFQ group was lower (marginally) than that of the low CFQ

⁸ We used the total CFQ scores for the correlation analyses. But, it is possible that the attention networks tap different factors in the CFQ. Factors of the CFQ have been studied but results are mixed (e.g., Larson et al., 1997; Matthews, Coyle, & Craig, 1990; Pollina, Greene, Tunick, & Puckett, 1992; Wallace, Kass, & Stanny, 2002). In our own study (Ishigami & Frankland, 2010), we found an oblique dfour factor solution. These factors were labeled General Attention, Interpersonal Relations, Task Oriented Attention, and Interpersonal Communication (tentative labels). We conducted further analyses to examine the relation between each network score and each factor score based on our four factor solution (Table 2.5). The network scores seemed to be correlated with General Attention and/or Task Oriented Attention. Orienting in error rate was significantly correlated with the total CFQ scores and General Attention.

group. However, interpreting this relationship requires caution for two reasons: 1) two components, namely exogenous and endogenous attention, are confounded in the ANT's measure of the efficacy of the orienting network, and 2) this pattern is confined to error rate and is not present in RT.

Alerting measured by the ANT is phasic alertness. Although not specifically advocated by its developers, we decided to use the ANTs to assess individual differences in tonic alertness. We did this by subtracting overall RT collapsed across condition in the first experimental block from RT in the last block (Sparkes, 2006). The rationale for this subtraction is that if a participant is losing his or her ability to sustain attention to the task at hand, RT and errors in most conditions should increase over time (Helton, 2009). Individual differences in tonic alertness as measured in this increase may be related to absentmindedness. Correlation analyses show that there was only a weak relationship between CFQ scores and the subtraction score (tonic alertness) in RT, $r = .177$, $p = .08667$, and there was none in error rate, $r = .146$.

Summary of Experiment 1

Consistent with Fan et al. (2002), the ANT was found to be a robust index of each attention network. The interaction between cue condition and target congruency suggests that the efficiency of the alerting and/or the orienting networks could modulate the efficiency of the executive network (see also Fan et al.). Although the correlation analyses revealed no significant correlations among the networks when using RT, the analysis of the error scores revealed that the executive network is related to the alerting and the orienting network. Network scores derived from the RT data did not correlate

with CFQ scores suggesting that the CFQ does not reflect the influence of a component of attention measured by the ANT. Somewhat attenuating this assertion, CFQ scores were found to have a significant negative correlation with the orienting network when measured using error rate. The pattern might be explained by saying that absentminded individuals are less able to make use of informative cues and thus show smaller orienting effects in error rate.

Experiment 2: Modified ANT (Callejas et al., 2005) and CFQ

In Experiment 2 the relationship between the components of attention and the CFQ will be reexamined using a modified ANT (Callejas et al, 2005). The alerting network is defined by auditory signals (tone and no tone) and is calculated by subtracting performance of the tone condition from performance of the no tone condition. The orienting network is defined by the uninformative visual cue (valid, invalid, and no cue) and is calculated by subtracting performance of the valid cue condition from performance of the invalid cue condition. The executive network is defined by target congruency (congruent and incongruent) and the calculation of the executive network is the same as the ANT.

Method

Participants

One hundred and one students at Dalhousie University (72 females and 29 males) participated as a part of a psychology class laboratory, for extra credit or for money. All participants had normal or corrected-to-normal vision.

Apparatus and Materials

CFQ. See Experiment 1.

Modified Attention Network Test (modified ANT). We used the program (E-prime) written by Callejas et al. (2005)⁹. A Pentium 4 computer with a 15" LCD display and a AMD Athlon (tm) 64 computer with a 16" LCD display controlled stimulus presentation and response collection. Responses were made via two keys ('C' and 'M') on a keyboard that was located in front of the participants. Earphone sets were used to deliver auditory alerting signals for the participants who were tested as a group. Stimuli were a fixation cross, a tone (2000 Hz and 50 ms sound) as an alerting signal, an asterisk (~ 0.40° visual angle) as an orienting cue, and arrows (~ 1.10° visual angle in length with ~ 0.30° visual angle distance between two arrows) as a target and distractors, pointing either leftward or rightward (Figure 2.1.2). The target array was ~6.95° visual angle long. All of them were black presented on a light gray background.

Procedure and Design

Except as noted the procedure and design are the same as for Experiment 1.

Modified ANT. The participants were tested as a group in an ordinarily lit room (for Pentium users) or were tested individually in a dimly lit testing room (for AMD Athlon users). The monitor was located approximately 60 cm from the participants' eyes although no restrictions were placed on the participants' movements. The fixation cross was presented for 400 – 1600 ms in the center of the screen at the beginning of the block and remained until the end of the block (Figure 2.1.2). Then, the auditory signal was

⁹ We thank Callejas for supplying this.

presented for 50 ms in half of the trials. After 450 ms from the onset of the auditory signal, the visual cue was presented for 100 ms above or below the fixation cross on two thirds of the trials. There were three types of cue: valid, invalid, and no cue. A cue could be presented at the same location as the target (valid), could be presented opposite from the target location (invalid), or could be absent (no cue). These cues were not informative regarding the target location. After 500 ms from the onset of the visual cue, the target array was presented above or below the fixation cross until the participant responded, but for no longer than 1700 ms. There were two types of target array: congruent and incongruent. The direction of the target arrow and the flanking arrows could be the same (congruent) or different (incongruent). The participants' task was to identify the direction of the target arrow, pressing the "C" key on the keyboard when the target arrow pointed left and the "M" key when the target arrow pointed right. After participants made a response, the target and the flankers disappeared immediately, followed by the second fixation period (3500 ms minus the first fixation period minus RT). The duration of each trial was 4450 ms.

The experiment contained seven blocks. A practice block (24 trials) was followed by six experimental blocks (48 trials/block) blocks. Auditory signal, visual cue, and target congruency conditions were orthogonally crossed in the experimental blocks. The 12 possible combinations of auditory signal, visual cue, and target congruency were pseudo-randomly presented so that there were four trials for each combination in a block. The number of trials in this experiment was the same as that in Experiment 1's three 96-trial experimental blocks.

Participants were instructed to maintain fixation at the fixation cross all the time, to identify the direction of the target (central) arrow and that quick and accurate responses would be important. Feedback following errors was given visually only in the practice block. The experiment lasted about 45 minutes.

Results and Discussion

Absentmindedness-CFQ

The total CFQ scores from 94 participants¹⁰ were available and analyzed (67 females and 27 males). The mean score was 41.6 ($SD = 10.7$). The distribution of CFQ scores in our sample is shown in (Figure 2.2).

Attention - Modified ANT

The data from five participants were excluded for the same reason as in Experiment 1, resulting in analyzing the data of 96 (69 females and 27 males) participants (age range 17 – 41, mean age 22). For each participant, error rate and mean correct RT after eliminating extreme values (less than 200 ms and more than 1200 ms: 0.7% of the total) were computed and subjected to analyses. Table 2.2 and Figure 2.3 summarize mean correct RT and error rate.

Mean correct RT and mean error rate were submitted to ANOVAs with auditory signal (tone and no tone), visual cue (valid, invalid, and no cue), and target congruency (congruent and incongruent) as repeated-measures factors. The main effects of auditory signal, $F(1, 95) = 170.24$, $MSe = 919$, $p < .0001$, visual cue, $F(2, 190) = 436.66$, $MSe = 659$, $p < .0001$, and target congruency, $F(1, 95) = 1150.1$, $MSe = 2083$, $p < .0001$, were

¹⁰ One participant missed one question out of 25 questions. So, the mean of her total score based on the 24 questions was calculated and it was added to her existing total score. The new total score was used for later analyses.

significant. Here it can be seen that participants were fast to respond to the target in the presence of auditory signals, valid cues, and congruent distractors. Interactions were analyzed excluding data from the no cue (visual cue) trials because the no cue condition was not relevant for measuring the orienting network (Callejas et al., 2005). The interaction between visual cue and target congruency was significant, $F(1, 95) = 75.09$, $MSe = 450$, $p < .0001$, suggesting that the congruency effect (incongruent-congruent) was greater for the invalid than for the valid condition (Figure 2.3). The interaction between auditory signal and visual cue was significant, $F(1, 95) = 49.95$, $MSe = 387$, $p < .0001$, suggesting that the cueing effect (invalid-valid) was greater for the tone (64.5 ms) than no tone (44.4 ms) conditions. The interaction between auditory signal and target congruency was significant, $F(1, 95) = 52.156$, $MSe = 356$, $p = .0001$, suggesting that the congruency effect was greater for the tone than no tone conditions (Figure 2.3)¹¹. The three-way interaction between auditory signal, visual cue, and target congruency was significant, $F(1, 95) = 4.7844$, $MSe = 258.8$, $p = .03117$. Separate ANOVAs for the valid and invalid conditions showed that greater congruency effects for the tone than the no tone conditions were even more evident for the invalid condition, $F(1, 95) = 42.534$, $MSe = 345$, $p < .001$, than the valid condition, $F(1, 95) = 18.945$, $MSe = 269.2$, $p < .001$. The interactions precisely replicated the ones reported by Callejas et al. in which the executive network was inhibited by the alerting network (see also Posner, 1994), but facilitated by the orienting network (see also Funes et al., 2007). In addition, the orienting effect was larger

¹¹ A subsequent analysis was carried out excluding the valid and invalid visual cue conditions. This ensures that the alerting effects from auditory signal are not confounded by the alerting effects from visual cue (Callejas et al., 2005). As was reported by Callejas et al. (2005) there was an even clearer interaction between the auditory warning and congruency when there was no opportunity for participants to use the visual cue to prepare for the visual target, $F(1, 95) = 60.924$, $MSe = 343$, $p < .0001$ (see also Callejas et al.).

when participants were alert (see also Sturm et al., 2006; Thimm et al., 2006).

For error rate, the main effects of auditory signal, $F(1, 95) = 7.9218$, $MSe = .001279$, $p < .005938$, visual cue, $F(2, 190) = 42.015$, $MSe = .001497$, $p < .0001$, and target congruency, $F(1, 95) = 98.781$, $MSe = .00337$, $p < .0001$, were significant. Here it can be seen that participants were more accurate in the absence of auditory signal, and in the presence of valid cues and congruent distractors. Interactions were analyzed excluding data from the no cue trials as was done for RT. The interaction between visual cue and congruency was significant, $F(1, 95) = 38.703$, $MSe = .001748$, $p < .0001$. The interaction between auditory signal and congruency was significant, $F(1, 95) = 5.2113$, $MSe = .001128$, $p = .02467$. The three-way interaction between visual cue, auditory signal, and target congruency was significant, $F(1, 95) = 4.9439$, $MSe = .001383$, $p = .02855$. Separate ANOVAs for the valid and invalid conditions showed that the interaction between auditory signal and target congruency was significant only for the invalid condition, $F(1, 95) = 6.9539$, $MSe = .001826$, $p = .009771$. These interactions were similar to and reinforce those seen in RT. No other interactions were significant.

The most obvious pattern observed in RT and error rate is that performance was impaired when the targets were flanked by incongruent flankers, and this impairment was greatest following an auditory signal and following an invalid cue. Hence, both the alerting and the orienting networks modulated the degree of interference from the distracting information (Callejas et al., 2005; Fan et al., 2002; Funes et al., 2007; Posner, 1978). As in Experiment 1, RT decreased and error rate increased when an auditory signal was presented.

Attention Network Scores

Table 2.3 summarizes attention network scores based on RT and error rate. One sample *t*-tests show that all the network scores were significantly different from zero in RT, $ps < .0001$, and in error rate, $ps < .01$ replicating Experiment 1. Thus, these results confirm that the modified ANT provides a usable index of each network both in RT and error rate.

Correlational Analyses Among Networks

Table 2.4 shows the correlations among the alerting, orienting, and executive networks. There were no significant correlations in the analysis of the RT network scores, consistent with Experiment 1 and Fan et al. (2002). On the other hand, the correlations among the networks were all significant in error rate (Figure 2.4). The alerting and executive networks were negatively correlated and the orienting and executive networks were positively correlated, consistent with Experiment 1. Participants with greater congruency effects showed smaller alerting and greater orienting effects. The alerting and executive networks were negatively correlated; participants with greater orienting effects showed smaller alerting effects.

Modified ANT and CFQ

Correlations between CFQ scores and each network in the modified ANT were examined¹² (Table 2.4). When assessed using RT, alerting and CFQ scores were

¹² As in Experiment 1, the relationship between CFQ factors and network scores were examined (Table 2.5). Alerting in RT was significantly correlated with the total CFQ scores, General Attention, and Task Oriented Attention. In error rate, orienting was significantly correlated with the total CFQ scores and Task Oriented Attention. Executive control was not significantly correlated with the total CFQ scores, but it was significantly correlated with Task Oriented Attention. Attention networks are better tapped by items in the CFQ that measure General Attention and/or Task Oriented Attention, than by items that measure Interpersonal Relations or Communications in the both ANTs.

positively correlated (Figure 2.5.2); participants with higher CFQ scores showed greater alerting effects. This observation supported our prediction (Hypothesis 1). Absentminded participants seemed to react more strongly to the auditory signals thereby showing a larger alerting effect in RT. To examine the alerting scores for the participants with high and low CFQ scores, the participants were divided into two groups according to the median value of 42. Then, the mean alerting scores of the two groups were compared. Figure 2.6.2 shows that the mean alerting score of the high CFQ group was greater than that of the low CFQ group. When assessed using accuracies, orienting and absentmindedness were positively correlated (Figure 2.5.2); participants with higher CFQ scores showed greater orienting effects, a pattern that might be explained by assuming that those with higher CFQ scores have a tendency for their attention to be more easily captured by the uninformative peripheral cue. These observations are consistent with our prediction (Hypothesis 2). The mean orienting scores of the two groups according to the median split above were compared. In Figure 2.6.2 it can be seen that the mean orienting score of the high CFQ group was greater (marginally) than that of the low CFQ group.

As in Experiment 1, tonic alertness was assessed by examining the change in RT between the first and last third of the experiment. Consistent with Experiment 1, there was no relationship between the measure of tonic alertness and CFQ scores ($r = .037$ and $.094$ for RT and error rate, respectively).

Summary of Experiment 2

Consistent with Experiment 1 and Fan et al. (2002), the ANT was found to be a robust index of each attention network. The interaction between auditory cue and target

congruency, and visual cue and target congruency suggests that the efficiency of both the alerting and the orienting networks modulated the efficiency of the executive network, replicating Callejas et al. (2005). According to the correlation analyses, the efficiencies of the three networks were not as independent of each other as in Fan et al. CFQ scores were found to have a positive correlation with the alerting network in RT and the orienting network in error rate. Both observations were consistent with our predictions (Hypotheses 1 and 2). Auditory signals had a greater impact on response speed for people with higher CFQ scores than with lower CFQ scores.

General Discussion

We are going to discuss the results of the ANTs first. Then, we will discuss whether individual differences in absentmindedness, measured in the CFQ, is correlated with the components of attention measured by the ANTs.

ANTs

We observed that both the ANT and the modified ANT produced a robust index of each attention network (alerting, orienting, and executive control), replicating Fan et al. (2002). Examination of the data (Figure 2.3) shows that the participants were quick to respond but inaccurate when alerted regardless of the type of alerting signals (visual in the ANT and auditory in the modified ANT); quick to respond and accurate when given a spatial cue regardless of its informativeness; slow and inaccurate in the presence of distracting incongruent information. The speed-accuracy tradeoff when alerted is consistent with Posner's suggestion (1975, 1978, Posner et al., 1973) that the effect of alertness is primarily a change in response speed without any improvement in the

information on which the response is based.

The functional independence of the three networks in the ANT and the modified ANT was examined in two ways (ANOVAs and correlation analyses), following the method by Fan et al. (2002) and Callejas et al. (2005). In the ANT, the interaction between cue condition and target congruency, which replicated the pattern found in Fan et al. (2002), suggests that the networks do not operate independently in all situations; the alerting and/or orienting effects may modulate the degree of interference from the distracting information. In particular, it appears that there is less interference from incongruent distractors when participants have not received a cue or when the cue was valid. The findings from the modified ANT agree with this pattern but because of the separation of alerting signal (tone) and spatial cue, it is suggested that directing attention in advance to the target location in the valid condition helps to filter out the distracting flankers (Fan et al., 2002; Funes et al., 2007). Why is the congruency effect similarly reduced (if not more so) in the condition with the lowest level of alertness (no tone and no spatial cue)? It is difficult to say, but we believe that the state of preparedness is simply incompatible with the caution associated with filtering (Posner, 1994).

In the modified ANT, the interaction between alerting and orienting was significant; the orienting effect was larger when participants were alert. This pattern is consistent with Callejas et al. (2005), Sturm et al. (2006) and Thimm et al. (2006) in suggesting that the alerting network could facilitate faster and perhaps more consistent orienting. The no tone condition, as the low-alertness condition, leads to longer RT, providing additional time for orienting attention to operate in the presence of the uninformative cue. These patterns

are consistent with Callejas et al. (2005) and further support the suggestion that processes of the three attention networks operate interactively.

In both versions of the ANT none of the networks assessed via RT were correlated with each other. However, when assessed via error rate, the alerting and the executive networks, and the orienting and the executive networks were correlated in both ANTs, and the alerting and the orienting networks were correlated in the modified ANT (Figure 2.4). In both versions of the ANT those who showed greater congruency effects showed smaller alerting effects and greater orienting effects. However, these results should be interpreted with caution due to the large number of relationships examined.

ANT & CFQ

The most consistent pattern between the ANT and CFQ scores in Experiments 1 and 2 is the null relationship between the executive network and CFQ scores for both RT and error rate. This is inconsistent with Hypothesis 3 that the high CFQ group might be more distracted by the flankers. Our results are pertinent to the discrepancy in the literature which has combined the flanker task with the CFQ: Using targets and distractors in known locations Broadbent et al. (1986) found no correlation while Forster and Lavie (2007) and Tipper & Baylis (1987) using unknown locations found a significant correlation. As discussed above, it was possible that this discrepancy is due to a mediating role for target and/or distractor location uncertainty. However, in the modified ANT target and distractor location are always uncertain and in this condition our findings agree with Broadbent's failure to find a correlation; therefore target location uncertainty is not the key to understanding the discrepancy. Without further research an

explanation for the discrepant findings cannot be endorsed with any confidence.

We found a significant positive correlation between CFQ scores and the alerting network in RT measured in the modified ANT (Figure 2.5.2). Higher CFQ scores were associated with greater alerting effects. Similarly, when comparing the low and high CFQ groups, the alerting effects in RT were significantly greater for the high CFQ than the low CFQ groups (Figure 2.6.2). These findings are consistent with our prediction (Hypothesis 1); those who had higher CFQ scores seem to react more strongly to salient warning stimuli. Because the same effect was not observed in error rate, the high CFQ group was not sacrificing accuracy for speed in order to show the faster responses when alerted by the tone. CFQ scores were not related to the alerting network in the ANT. This difference between the two ANTs might be due to the fact that the auditory signal in the modified ANT was more alerting for the high than the low CFQ participants even though they could be ignored. In contrast, the visual signals in the ANT, which should be attended because targets are visual and occasionally the cue would indicate the location of the target, alerted the high and low CFQ participants equally.

Lastly, we found that the orienting network as measured via RT was not related to CFQ scores, but was related to CFQ scores in error rate with both ANTs. The direction of the relationship is negative with the ANT and positive with the modified ANT. Thus, our predictions (Hypothesis 2) are supported. This difference may be due to the different components involved in the orienting network for the two ANTs. In the ANT, the spatial cue is 100 % valid. Thus, orienting can include both endogenous and exogenous components. The higher CFQ participants showed smaller orienting effects than the

lower CFQ participants with this 100% informative cue. This could mean that the higher CFQ participants did not use the cue's meaning as effectively as the lower CFQ participants (e.g., poor selective attention in the higher CFQ participants, see also Colflesh & Conway, 2007). This is consistent with Broadbent et al. (1986) who found a weak tendency for the high CFQ group to perform more poorly than the low CFQ group when target location was known. On the other hand, in the modified ANT, the visual cues are not informative; orienting includes only exogenous component. The higher CFQ participants showed greater orienting effects than the lower CFQ participants with this uninformative cue. Peripheral cues may cause a more automatic shift of attention for the high CFQ group. Alternatively, low CFQ participants may establish a more effective attentional control setting to ignore the uninformative peripheral cues (e.g., greater selective attention, see also Conway, Cowan & Bunting, 2001). Thus, absentminded people may fail to take advantage of prior knowledge of target location (ANT), and fail to ignore automated actions (modified ANT). As with the analyses among the network scores, however, these results must be interpreted cautiously due to the large number of relationships examined.

Conclusion

The current study replicated the methods of the ANTs used by Fan et al. (2002) and Callejas et al. (2005). Consistent with these studies, the ANT was found to be a robust measure of attention networks (alerting, orienting, and executive control). These networks operate interactively. Contrary to our expectation, we did not find clear links between CFQ scores and executive control. There were links between CFQ scores and

the alerting and the orienting networks. High CFQ individuals show larger alerting effects (RT reductions) from the tone in the modified ANT. Orienting effects measured in error rate but not in RT were larger for high CFQ individuals when the cues were uninformative (modified ANT) but smaller for the high CFQ individuals when the cues were 100% informative (standard ANT). We interpret these effects by assuming that absentminded people are more strongly responsive to irrelevant external stimuli and may less able to take an advantage of prior knowledge.

Table 2.1
Summary of studies that examined relationships between CFQ scores and attention measures

Studies	Task	Author's categorization	Attention network type	N	Age (range or mean)	Results
Farrin et al. ¹				102	22-58	√ & ns
Manly et al. ²	SART	Sustained attention to response	Executive	60	18-65	√ & ns
Robertson et al.				75	18-65	√
Wallace et al.				151	21.7	ns
Broadbent et al.	Flanker task (E1 – 6)*	Focused attention ³	Executive	112	18-50	ns
	Flanker task (E1 & 2)	Search ⁴	Orienting	40	18-50	√
Forster & Lavie ⁵	Response-competition task*	Focused attention	Executive & orienting	61	19-38	√ & ns
Martin	Stroop*	Focused attention	Executive	32	na	ns
Tipper & Bayliss	Semantic flanker task*	Selective attention	Executive	32	na	√
	Semantic flanker task* ⁶		Other ⁷	32	na	√ & ns
	Negative priming task* (E1)		Executive	40	17-25	ns
	Negative priming task* (E2)	Inhibition	Other	39	62-78	ns
Kane et al.			Executive	20	64-77	ns
			Other			ns
	Flanker task*		Executive			√
	Negative priming task*		Orienting & other	32	18-28	√
Kramer et al. ⁸	Stopping*	Inhibition	Executive & tonic alerting	30	60-74	ns
	WCST*		Executive			√
Roche et al. ⁹	Go/NoGo	Response inhibition	Executive & tonic alerting	20	17-31	ns
Vom Hofe et al.	Stroop*	Inhibition	Other	87	20-49	√
	Tipper localization task*			87	20-49	√
Harris & Wilkings ¹⁰	Test-Wait-Test-Exit task	Remembering to do things	Executive & tonic alerting	29	na	√ & ns
Martin & Jones ¹¹	Dual task	Distributed attention	Executive	20	18-35	√

√; A relationship between CFQ scores and measures of attention was found in the direction that the high CFQ scores were associated with poor performance unless noted
ns; A relationship between CFQ scores and measures of attention was not found
na: not available
*; task requiring filtering distracting information

¹ CFQ scores and false alarms in SART were not correlated when controlling for depression scores.

² There was a difference in false alarms between the high and low CFQ groups when the probability of the infrequent digit was low (0.11 probability); but there was no difference in false alarms between these groups when the probability of the infrequent digit was high (0.5 probability).

³ These authors measured differences between congruent and incongruent distractor conditions in the flanker task.

⁴ These authors measured differences between known and unknown target location conditions without distractors in the flanker task. There was a negative correlation between CFQ scores and the difference scores.

⁵ The high CFQ group responded more slowly in identifying a target when perceptual load was low (e.g., the target was presented among five 'O's along an imaginary circle). Yet, when perceptual load was high (e.g., the target was presented among five different letters), there was no difference between the high and low CFQ groups.

⁶ The low CFQ participants showed presence of negative priming, but not the high CFQ participants. There was no difference in positive priming in these groups.

⁷ When negative priming was a measure of interest, we categorize its attention network type as 'other' because negative priming could involve memory components, which is different from concurrent attention functions we are interested in studying.

⁸ Thirty-two younger adults and thirty older adults performed a series of inhibition tasks. Age was partialled out of each of the correlation results.

⁹ Whereas their behavioral measure of executive control was not linked to CFQ scores, their event-related brain potentials (ERP) recordings showed differences between the high and the low CFQ groups; a larger P3b component following errors was found for the high CFQ group (see also Garavan, Ross, Murphy, Roche, & Stein, 2002).

¹⁰ When participants were asked to watch a film and hold up sheets of paper at preset times that were written on each sheet, the participants with higher CFQ scores were more frequently late to hold up the sheet than participants with lower scores. However, CFQ scores were not related to the number of times the participants looked back to see a clock behind them.

¹¹ When auditory detection and reading tasks were performed together, the participants with higher CFQ scores were slower on the detection task and faster on the reading task than participants with lower scores.

Table 2.2

Mean RT (ms), mean error rate (proportion incorrect), and standard deviations (SD) (between parenthesis).

Experiment 1

		No cue	Center	Double	Spatial
RT	Congruent	591 (66)	556 (67)	544 (64)	520 (62)
	Incongruent	701 (85)	687 (78)	677 (80)	634 (76)
	Neutral	569 (60)	513 (59)	503 (54)	476 (54)
Error rate	Congruent	0.008 (0.019)	0.008 (0.020)	0.010 (0.021)	0.007 (0.022)
	Incongruent	0.060 (0.068)	0.093 (0.096)	0.107 (0.103)	0.065 (0.081)
	Neutral	0.020 (0.030)	0.017 (0.026)	0.016 (0.024)	0.012 (0.029)

Experiment 2

		Tone			No tone		
		Valid	Invalid	No cue	Valid	Invalid	No cue
RT	Congruent	464 (67)	513 (78)	484 (67)	496 (79)	530 (86)	538 (79)
	Incongruent	552 (78)	632 (89)	582 (84)	570 (80)	626 (91)	607 (92)
Error rate	Congruent	0.004 (0.033)	0.007 (0.042)	0.008 (0.044)	0.004 (0.033)	0.012 (0.055)	0.010 (0.049)
	Incongruent	0.026 (0.088)	0.078 (0.144)	0.042 (0.106)	0.026 (0.080)	0.060 (0.130)	0.018 (0.066)

Table 2.3

Network scores based on RT (ms) and error rate (proportion incorrect) for alerting, orienting, and executive networks in Experiments 1 and 2.

		Alerting	Orienting	Executive
Experiment 1	RT	47.8	40.8	121.4
	Error rate	-0.015	0.012	0.073
Experiment 2	RT	24.1	53.0	90.8
	Error rate	-0.006	0.024	0.034

Table 2.4

Correlations between attention networks in RT (ms) and error rate (proportion incorrect).

Experiment 1

RT	Alerting	Orienting	Error rate	Alerting	Orienting
Orienting	0.081		Orienting	0.009	
Executive	0.19	-0.029	Executive	-0.365***	0.224**

Experiment 2

RT	Alerting	Orienting	Error rate	Alerting	Orienting
Orienting	0.06		Orienting	-0.278**	
Executive	0.116	0.033	Executive	-0.372***	0.508***

- * Correlations is significant at the 0.05 level
- ** Correlations is significant at the 0.01 level
- *** Correlations is significant at the 0.001 level

Table 2.5

Correlations between CFQ and CFQ factor scores and the attention networks for RT and error rate in Experiments 1 and 2.

	Exp	DV	CFQ total	F1	F2	F3	F4
Alerting	1	RT	-0.184	-0.172	-0.019	-0.169	-0.068
	1	Error	0.037	-0.007	-0.106	0.074	0.179
	2	RT	0.272**	0.262*	-0.122	0.248*	0.19
	2	Error	0.138	0.098	0.079	0.056	0.137
Orienting	1	RT	0.182	0.178	0.067	0.137	0.026
	1	Error	-0.208*	-0.250*	-0.052	-0.074	-0.087
	2	RT	0.086	0.095	-0.08	0.05	0.099
	2	Error	0.234*	0.099	0.127	0.269**	0.138
Executive	1	RT	0.089	0.127	0.027	0.071	-0.124
	1	Error	0.017	0.039	0.101	-0.025	-0.092
	2	RT	0.116	0.032	0.115	0.11	0.072
	2	Error	0.162	-0.003	0.202	0.216*	0.108

* Correlations is significant at the 0.05 level

** Correlations is significant at the 0.01 level

F1: General attention

F2: Interpersonal relations

F3: Task oriented attention

F4: Interpersonal communication

Figure 2.1.1

(A) Experimental procedure of the ANT (Fan et al., 2002). (I) the four cue conditions, (II) the six target stimuli used in the present experiment, and (III) An example of the procedure; a spatial cue is presented followed by a target (central) arrow.

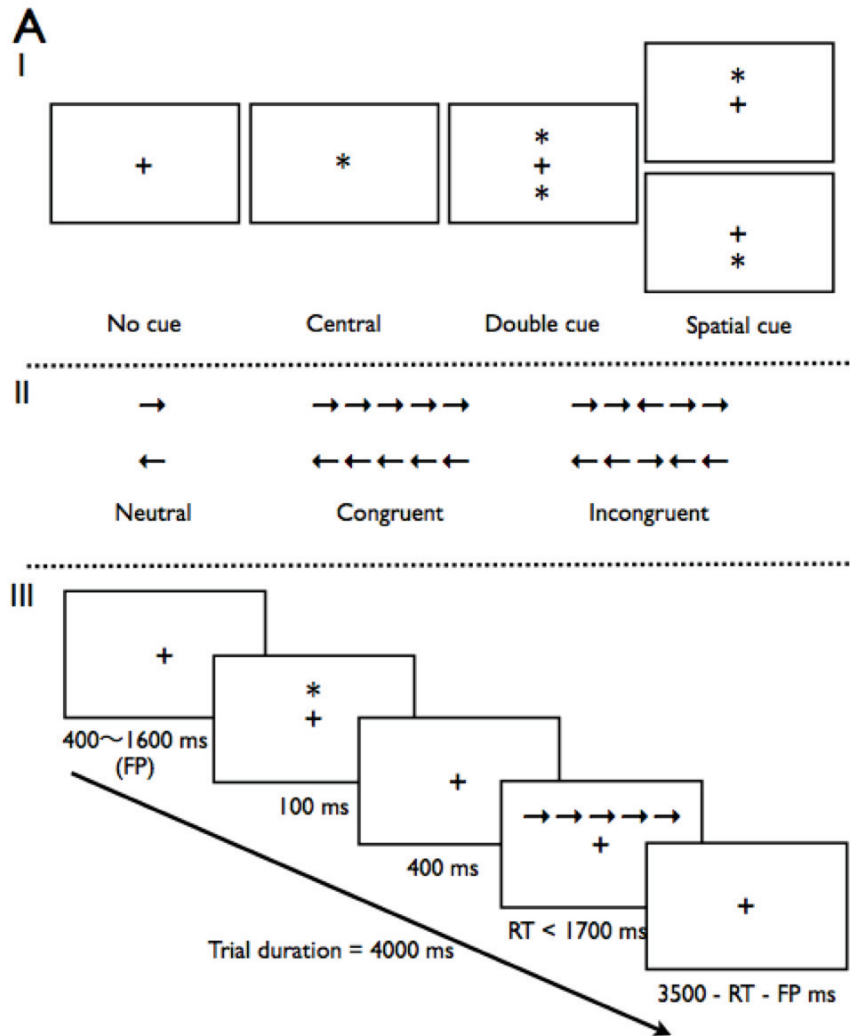


Figure 2.1.2

(B) Experimental procedure of the modified ANT (Callejas et al., 2005). An example of the procedure; an auditory tone is presented, followed by a valid cue, and a target (central) arrow flanked by congruent arrows.

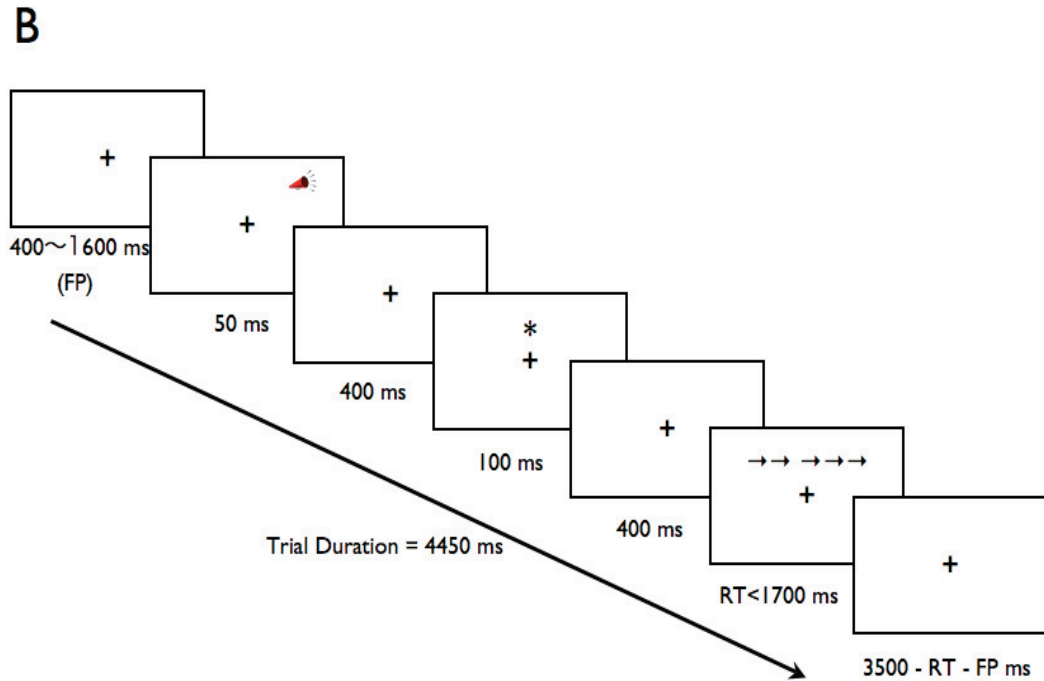


Figure 2.2
Frequency of CFQ scores for Experiments 1 (A) and 2 (B).

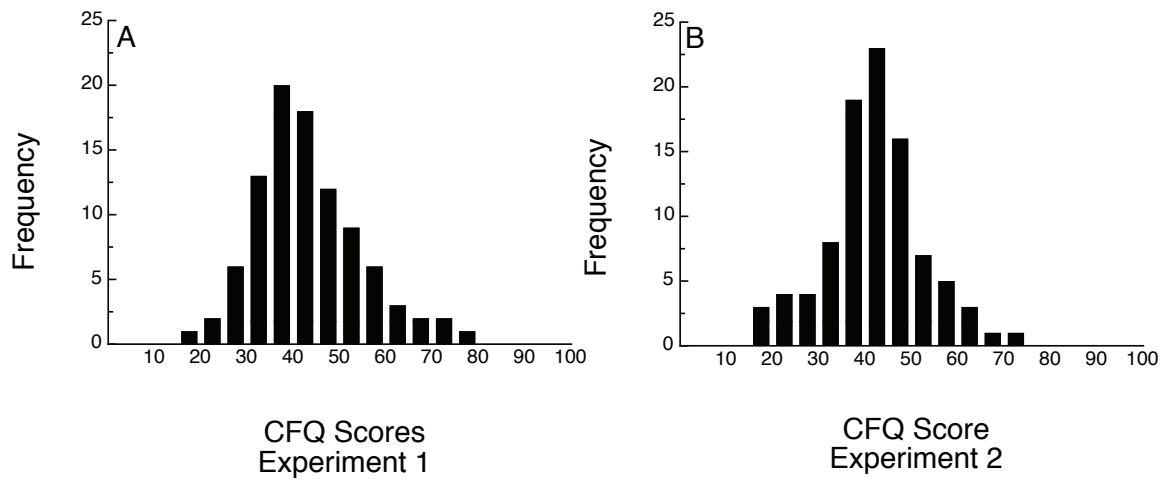


Figure 2.3

Mean correct RT (left) and error rate (right) on the ANT in each experiment. Data from Experiment 1 (A) are shown as a function of cue condition and target congruency. Data from Experiment 2 (B) are shown as a function of auditory warning signal, visual cue condition, and target congruency.

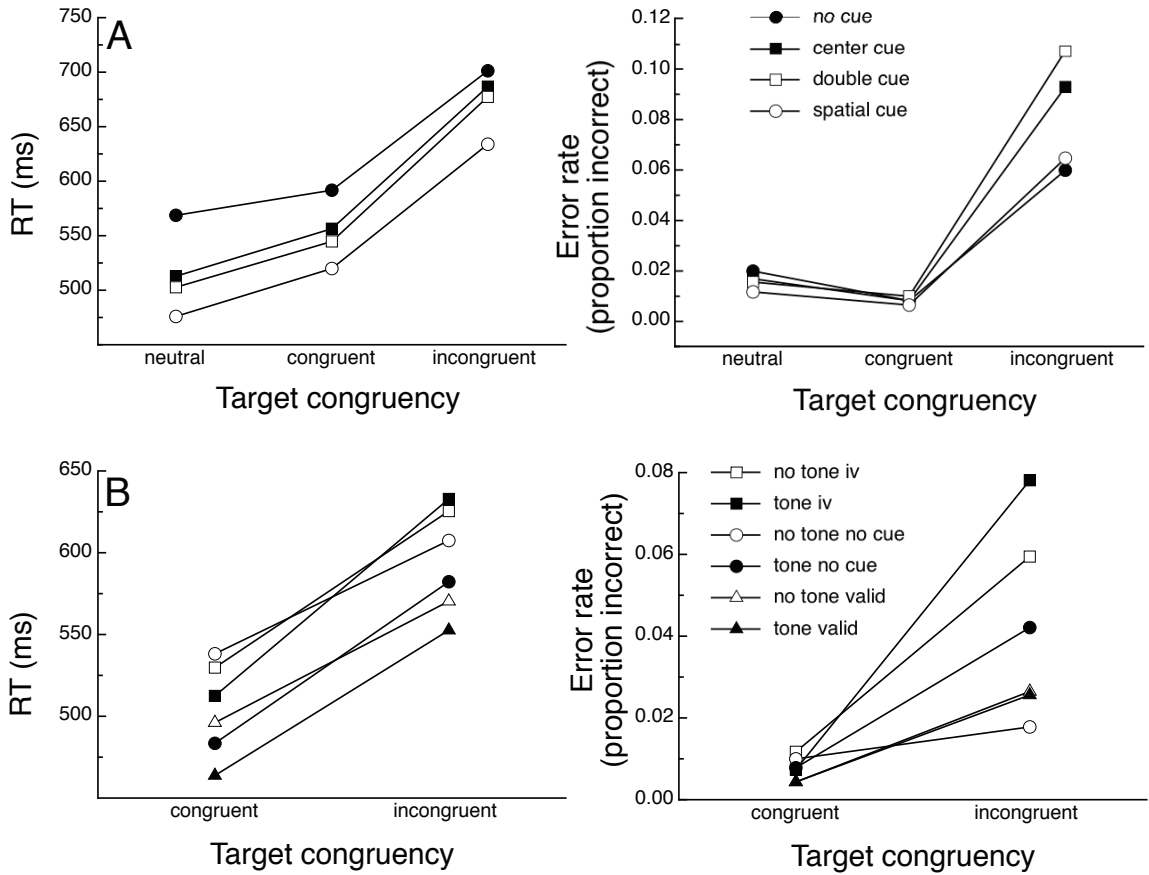


Figure 2.4
 Significant correlations among the networks in Experiment 1 (A and B) and Experiment 2 (C, D, and E).

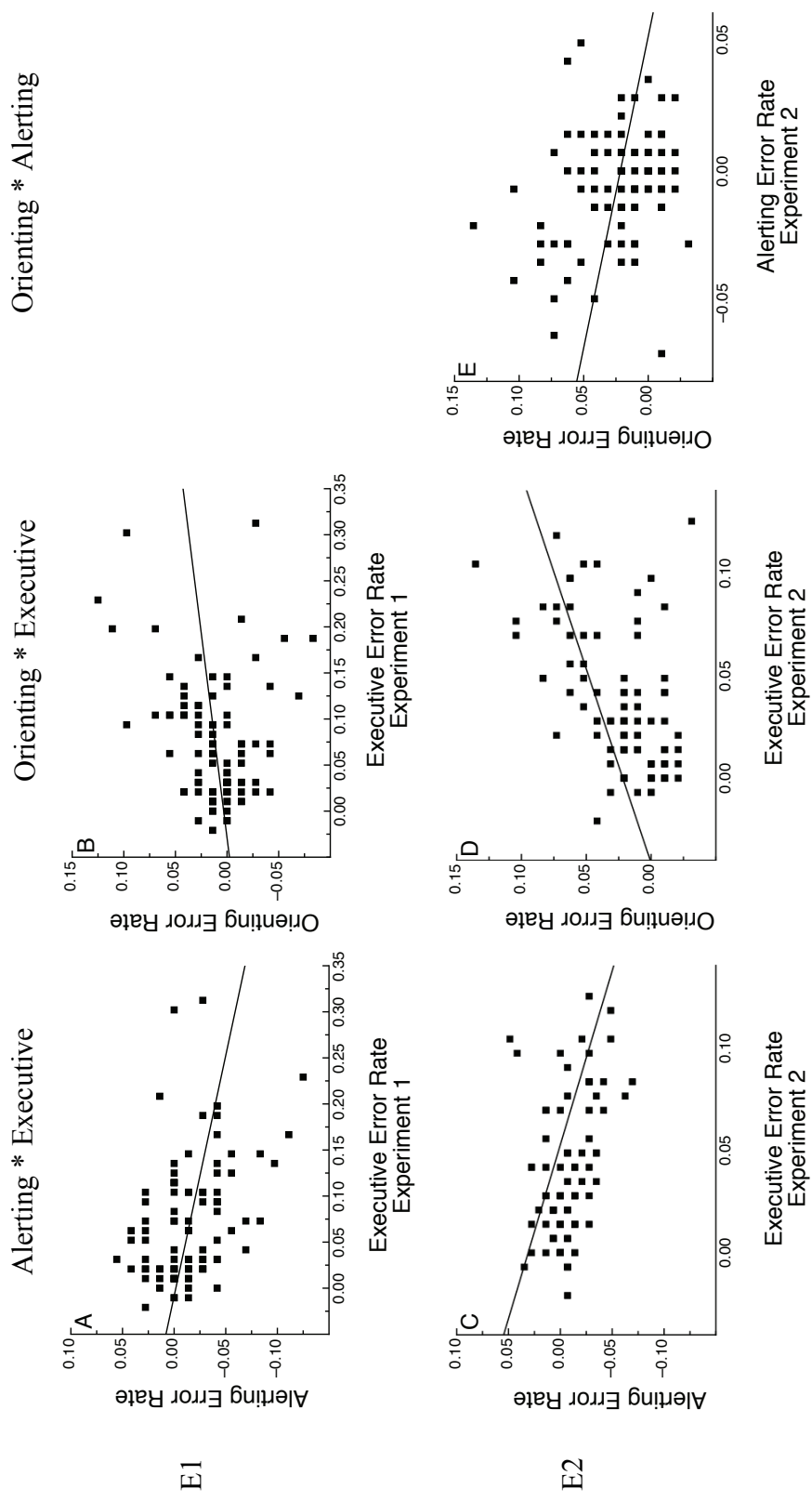


Figure 2.5.1

(A) Correlations between CFQ and ANT network scores (Experiment 1).

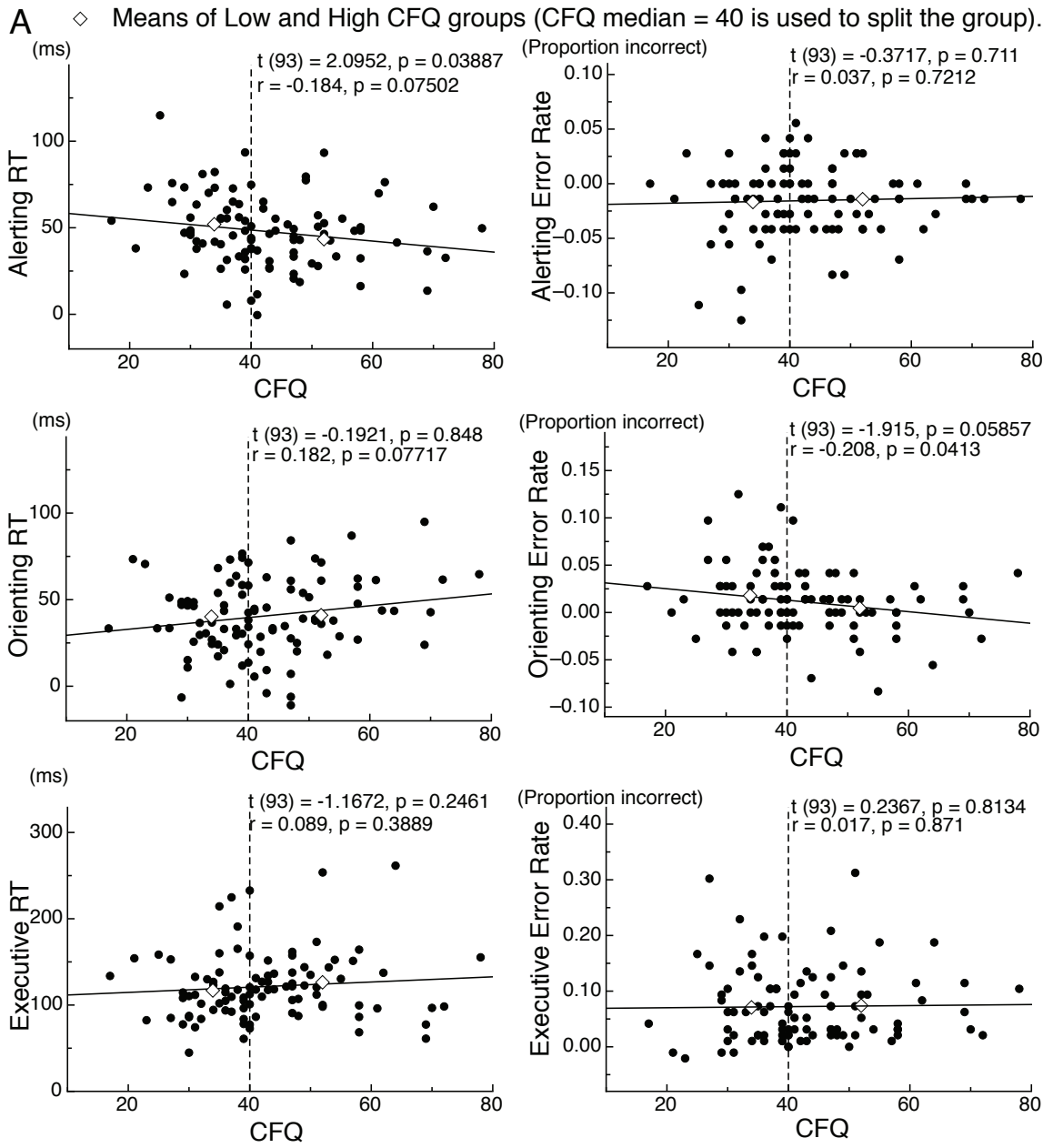


Figure 2.5.2

(B) Correlations between CFQ and modified ANT network scores (Experiment 2).

B ◇ Means of Low and High CFQ groups (CFQ median = 42 is used to split the group).

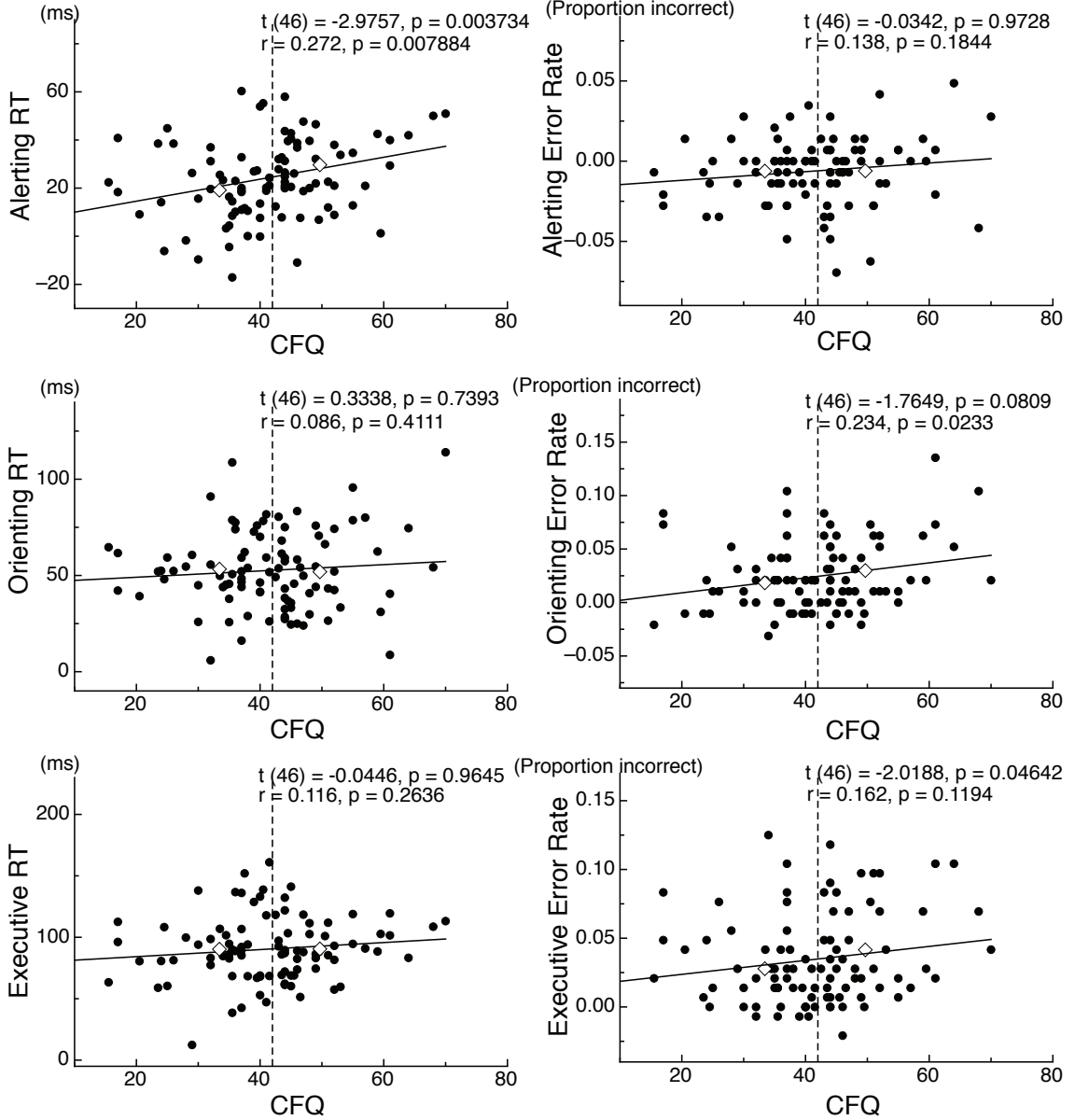


Figure 2.6.1

(A) Each network scores as a function of the CFQ groups in Experiment 1.

The participants were divided into two groups according to the median value of 40. The participants were divided into two groups according to the median value of 42. Error bars show half of the least significant difference (LSD) and can be easily interpreted such that non-overlapping bars show significant differences, $p = 0.05$.

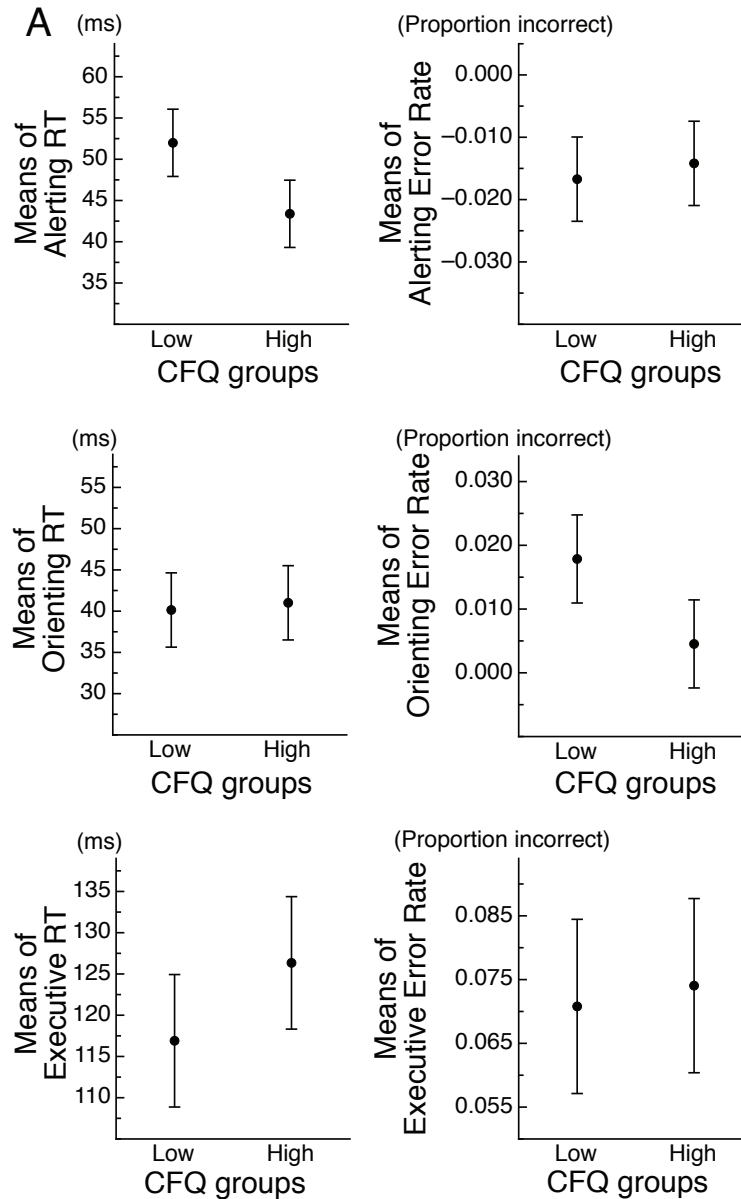
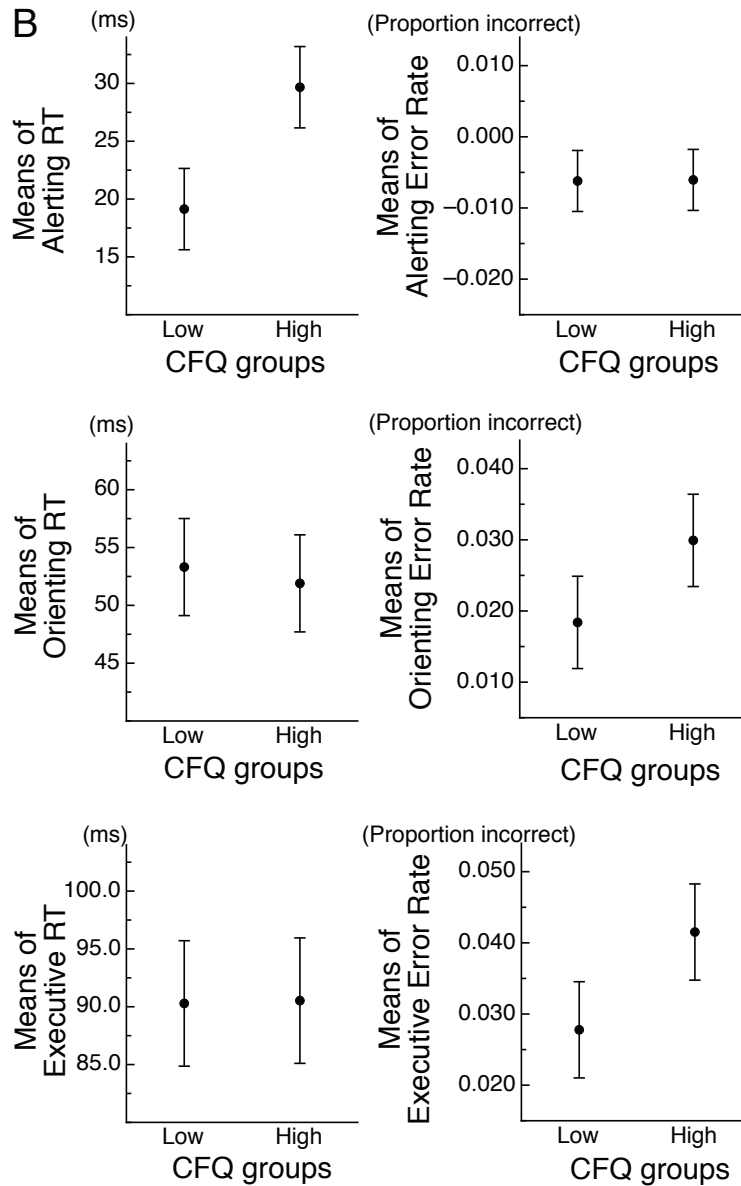


Figure 2.6.2

(B) Each network scores as a function of the CFQ groups in Experiment 2. The participants were divided into two groups according to the median value of 42. Error bars show half of the least significant difference (LSD) and can be easily interpreted such that non-overlapping bars show significant differences, $p = 0.05$.



CHAPTER 3:
REPEATED MEASUREMENT OF THE COMPONENTS OF ATTENTION OF
YOUNG ADULTS
USING THE TWO VERSIONS OF THE ATTENTION NETWORK TEST (ANT):
STABILITY, ISOLABILITY, ROBUSTNESS, AND RELIABILITY

The manuscript based on this study is presented below. Co-author for this manuscript is Dr. Raymond Klein.

The manuscript based on this study is presented below.

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Abstract

Using orthogonal subtractions of performance in selected conditions the attentional network test (ANT) measures the efficacy of three isolable components of attention: alerting, orienting, and executive control. Ten test sessions, each containing two versions of the ANT (Fan et al., 2002 and Callejas et al., 2005), were administered to 10 young adults to examine stability, isolability, robustness, and reliability of the tests. Participants indicated the direction of a target arrow presented either above or below the fixation. The target arrow was accompanied by distracting arrows, either pointing to the same direction (congruent) as or the opposite direction (incongruent) to the target arrow. The arrows were preceded by informative visual cues (center, double, spatial, and no cue) differing in temporal and spatial information (Fan et al.) or by alerting auditory signals (tone and no tone) and uninformative visual cues (valid, invalid, and no cue) (Callejas et al.). All network scores remained highly significant even after nine previous sessions despite some practice effects in the executive and the orienting networks. Some lack of independence among the networks was found. The relatively poor reliability of network scores with one session of data rises to respectable levels as more data is added.

Introduction

The original Attention Network Test (which we will refer to it simply as ‘ANT.’) was developed by Fan, McCandliss, Sommer, Raz, and Posner (2002) to measure three isolable attentional networks: alerting, orienting, and executive control. These networks are defined jointly in anatomical and functional terms, by finding correspondence between areas of activation in the brain and performance in attention tasks which measure different functions of attention. Alerting involves a change in mental state as well as some changes in physiological state. These changes follow the presentation of a signal that provides information that a task-relevant event will occur soon (Posner, 1978). Right hemisphere and thalamic areas are involved in alerting (e.g., Coull, Frith, Frackowiak, & Grasby, 1996; Sturm & Willmes, 2001). Orienting involves turning one’s attention to a source of signals in space (Posner, 1978). Areas of the parietal lobe, the midbrain, and the thalamus have been associated with this function (Posner & Raichle, 1994). Executive control involves conflict resolution and control over decision-making, error detection, and habitual response inhibition (Norman & Shallice, 1986). The anterior cingulate cortex and the lateral prefrontal cortex have been associated with this function (e.g., Bush, Luu, & Posner, 2000; Casey et al., 2000).

The ANT is a simple, yet carefully designed, test of performance in which specific subtraction scores are used to measure the efficiency of three different attention networks (Klein, 2003). On each trial, different types of warning cue precede a central target arrow, pointing either left or right, that is often flanked by distracting arrows (Figure 3.1.1). The participants’ task is to indicate the direction of the target arrow as quickly and accurately

as possible. The efficiency of the alerting and orienting networks are measured by comparing performance in the different types of cue condition (center, double, spatial, and no cues); the efficiency of the executive network is measured comparing performance in the different types of target congruency condition (congruent and incongruent) (Table 3.1). Fan et al. (2002) demonstrated that the ANT provides a reliable measure of each network (alerting, orienting and executive control). In addition, they suggested that each network was independent of the others by showing no significant correlations among the network scores. However, they also reported an interaction between the cue condition and target congruency (as have others, see e.g., Ishigami & Klein, 2009a/Chapter 2), suggesting some lack of independence among the networks. It is partly for this reason that we use the weaker term (from Posner, 1978) “isolable” when describing relationships among the three attention networks.

As noted by Callejas, Lupianes, Funes, and Tudela (2005) there are limitations of the ANT as described above. First, the alerting and the orienting networks are both defined by cue condition (i.e., alerting = double cue minus no cue conditions, orienting = center cue minus spatial cue conditions). Consequently, we cannot know whether the alerting and the orienting networks interact. Relatedly, we cannot separate a potential interaction between the alerting and orienting networks from the significant interaction between cue condition and target congruency, which Fan et al. (2002) reported. Second, their peripheral cue (spatial cue condition), one of the two cue conditions used to define the orienting network, predicts the target location with 100% validity. The combination of information value with peripheral cueing means that the measure of orienting (center

minus peripheral cue) has indeterminate contributions from exogenous and endogenous shifts of attention (Klein, 2004). In the model cueing task developed by Posner and colleagues (e.g. for reviews, see Posner, 1980; see Klein, 2005) orienting is measured as the difference in performance following a peripheral (or central arrow) cue between targets presented at the cued location versus targets presented at the opposite, uncued location. Importantly, in both of these conditions the participant's attention is in the same general state (captured by a peripheral cue or allocated in response to the central arrow cue) regardless of where the target is presented. Mental state is necessarily different with the use of a cue with 100% validity, which is compared to a neutral cue to generate a subtraction score (see Jonides & Mack, 1984, for a discussion of this problem).

Callejas et al. (2005) developed an alternative version of the ANT [we will refer to it as the Attention Network Test – Interactions (ANT-I)] to overcome these limitations (Figure 3.1.2, Table 3.1). As with the ANT, the orienting and executive networks are defined by the visual cue (valid and invalid) and target congruency (congruent and incongruent), respectively. However, the alerting network is defined by auditory signals (tone and no tone). The separation of the alerting (auditory) from the orienting (visual) cues permits the researcher using this task to explore performance as a joint function of orienting (valid vs invalid) and alerting (tone vs no tone). A secondary benefit of this change derives from the possibility that auditory signals have greater alerting effects than visual signals (Posner, 1978; Posner, Nissen & Klein, 1976). Thus, this design permits the researcher to examine the interaction among the networks with confidence. In addition, uninformative peripheral cues were used to define the orienting network in the ANT-I.

The use of uninformative peripheral cues allows the researcher to measure the effect of exogenous orienting while excluding the endogenous component. Callejas et al. reported statistical interactions among all the networks. The executive network is inhibited by the alerting network (see also Posner, 1994), but facilitated by the orienting network (see also Funes, Lupianez, & Milliken, 2007). In addition, the orienting network is facilitated by the alerting network especially when stimulus onset asynchrony (SOA) is short (i.e., 100 ms rather than 500 ms, which is used in the current study) (see also Sturm, Thimm, Kuest, Karbe, & Fink, 2006; Thimm, Fink, Kust, Karbe & Sturm, 2006). Thus, Callejas et al. concluded that the attentional networks in the ANT operate interactively.

Both versions of the ANT (i.e., the ANT and the ANT-I) provide convenient measures of attentional networks (alerting, orienting, and executive control). It takes only about 20 minutes to complete, and it is easily performed by children, older adults, brain damaged patients, and even monkeys (e.g., Beran, Washburn, & Kleinman, 2003; Jennings, Dagenbach, Engle, and Funke, 2007; Rueda et al., 2004). Thus, it can be used in variety of contexts (e.g., clinical, genetic, etc.) to address a wide range questions about attention. Indeed, since the original version of the ANT was introduced by Fan et al. (2002) versions of the test have been used in over 60 publications dealing with a wide range of topics and methods including: development, neuroimaging, pharmacology, genetics, psychiatric disorders, brain damage, individual differences, etc. One class of situation to which the ANT might be applied are those in which repeated testing is required. For example, Tang et al. (2007) examined effects of meditation training on alerting, orienting, and executive function (see also Jennings, Dagenbach, Engle, &

Funke, 2007). Eighty university students were randomly assigned to either an experimental or control group. The students in the experimental group received meditation training and the students in the control group simply received information about relaxation of each body part. The ANT was administered before and after five training or information sessions. The students in the experimental group showed more efficient executive function after the training sessions than the students in the control group while there were no differences in alerting and orienting between these two groups after the sessions. Thus, the ANT can be and has been used to evaluate effects of training on the components of attention. Researchers have also been interested in evaluating effects of attention training or rehabilitation on the specific components of attention in clinical populations (e.g., Pero, Incoccia, Caracciolo, Zoccolotti, & Formisano, 2006; Robertson, Tegner, Tham, Lo, & Nimmosmith, 1995; Serino et al., 2007, Sohlberg, McLaughlin, Pavese, Heidrich, & Posner, 2000; Sturm et al., 2006; Sturm, Willmes, Orgass, & Hartje, 1997; Thimm et al. 2006).

Despite the use of the ANT in pre-/post- testing (Jha et al., 2007; Tang et al., 2007) and its potential use in clinical settings (e.g., Robertson et al., 1995), how performance of the three attention networks changes over time with repeated administrations and whether performance in the two versions of the ANT (i.e., the ANT and the ANT-I) changes in the same way are not known. Thus, the primary objective of the current study is to examine the stability, robustness and reliability of the attention networks derived from both versions of the ANT over repeated testing. Once we had collected a large corpus of data it was also possible to examine the isolability of the

network scores derived from each version. A secondary objective was to compare the two versions of the ANT to determine if there were any substantial differences in their utility and to determine whether they were tapping the same three components of attention. The temporal stability of the scores was examined by Analysis of Variances (ANOVAs) with session as a factor to determine whether the magnitude of the score changed with practice on the task. The robustness of the scores was examined using one-sample *t*-tests to evaluate the significance of each component's score in the different testing sessions. Reliability (or intra-subject stability) was examined by computing for each score the correlation across different combinations of sessions (as will be described in more detail later). Finally, isolability was examined in two ways: by determining whether there were significant interactions among the measures of the networks in the ANOVAs and whether there were significant correlations among the three networks. In the current study, the aforementioned analyses were made possible by having each participant perform both versions of the ANTs on 10 different occasions.

Materials and Methods

Participants

Ten participants (eight females and two males) took part in the current experiment. Four participants were research assistants who volunteered to participate in this experiment. Six participants were students from the Dalhousie University psychology subject pool or students from other institutes and took part for money (\$10.00/hour). The participants ranged in age from 18 to 39, with a median age of 23. All participants had normal or corrected-to-normal vision. All participants completed an informed consent

form and the study was approved by the Dalhousie Social Sciences and Humanities Human Research Ethics Board.

Apparatus

Attentional Network Test (ANT). We used the program (Java) written by researchers at the Sackler Institute for Developmental Psychobiology (http://sacklerinstitute.org/cornell/assays_and_tools/). A 14-inch iMac controlled stimulus presentation and response collection.

Attentional Network Test - I (ANT-I). We used the program (E-prime) written by Callejas et al. (2005)¹³. An AMD Athlon (tm) 64 computer with a 16" LCD display controlled stimulus presentation and response collection.

Stimuli, Procedure and Design

The sequence of events in both tests can be seen in Figures 3.1.1 and 3.1.2. For more specific details we refer the reader to the original papers by Fan et al. (2002), Callejas et al. (2005), or Ishigami and Klein (2009a/Chapter 2). The experiment contained four blocks for the ANT and seven blocks for the ANT-I. A practice block (24 trials) was followed by experimental blocks (96 trials/block for the ANT and 48 trials/block for the ANT-I). Cue condition and target congruency conditions for the ANT and auditory signal, visual cue, and target congruency conditions for the ANT-I were orthogonally crossed in the experimental blocks. The 12 possible combinations from each condition were pseudo-randomly presented so that there were eight trials and four trials for each combination in a block for the ANT and the ANT-I, respectively.

¹³ We thank Alicia Callejas for supplying this.

Task Administration

The instructions (both verbal and written) emphasized the importance of quick and accurate responding. The participants were told to maintain fixation at the fixation cross all the time. However, they were encouraged to attend when and where indicated by the cues in the ANT. The experimenter was present at the beginning of the experiment in the testing room to start the experiment (i.e., start the program on the computer) and to answer participants' questions regarding the instructions on only earlier sessions. After a couple of the sessions, the participants started the experiment upon arriving the testing room without the presence of the experimenter. In both the ANT and the ANT-I, feedback following errors was given visually only in the practice blocks. Participants performed both versions of the ANT (ANT and ANT-I) in each session, which lasted about an hour and this was repeated 10 times (i.e., 10 days). The ANT and the ANT-I were administered in an alternating order across sessions. In addition, the order of the ANTs was counterbalanced across the participants. Intervals between two consecutive sessions were not fixed and the mean interval was 8.6 days (SD = 15.7).

Results

ANT

For each participant, mean correct RT after eliminating extreme values (less than 200 ms and more than 1200 ms: 1.4% of the total) and mean error rate were computed and subjected to analyses. Table 3.2 shows mean correct RT and error rate collapsed across session, and Figures 3.2.1-2 shows mean correct RT and error rate for cue condition and target congruency as a function of session.

Stability and Isolability of the Network Scores

In order to allow comparison with the literature (which typically only has one session) analyses were done separately for Session 1 and Sessions 1-10. Stability (do effects change over the 10 sessions?) was examined with ANOVAs and isolability (do conditions interact?) was examined by both ANOVAs and correlation analyses.

ANOVAs

The mean correct RT and the mean error rate were submitted to ANOVAs with cue condition (center, spatial, double, and no cues), and target congruency (neutral, congruent, and incongruent) as repeated-measures factors [and Session (1-10) for the Sessions 1-10 analyses].

Session 1 (Figure 3.3.1). For RT, the main effects of cue condition, $F(3, 27) = 28.79, p < .0001$, and target congruency, $F(2, 18) = 211.05, p < .0001$, were significant. The interaction between cue condition and target congruency was significant, $F(6, 54) = 4.45, p < .0001$, reflecting some lack of independence among the networks. Here it can be seen that the congruency effect (incongruent-congruent) was greater when participants were alerted by non-spatial cues (double and center cues).

For error rate, the main effect of target congruency was significant, $F(2, 18) = 22.54, p < .0001$. The main effect of cue condition was marginally significant, $F(3, 27) = 2.49, p = .081$. The interaction between cue condition and target congruency was almost significant, $F(6, 54) = 2.27, p = .051$. It can be seen in Figure 3.3.1 that the interaction was similar to and reinforces that seen in RT; the negative impact of distractors was greater in the presence of non-spatial cues.

Sessions 1 - 10 (Figure 3.3.2). For RT, the main effect of session was not significant, $F(9, 81) = 1.14$. The main effects of cue condition, $F(3, 27) = 94.87, p < .0001$, and target congruency, $F(2, 18) = 152.15, p < .0001$, were significant. The interaction between cue condition and target congruency was significant, $F(6, 54) = 22.99, p < .0001$, reflecting some lack of independence among the networks. In addition, the interaction between session and target congruency was significant, $F(18, 162) = 7.01, p < .0001$, reflecting a learning effect that was due mainly to an improvement in the incongruent condition (see Figure 3.2.2). The learning effect for the executive network was examined by running a separate ANOVA. The mean executive network scores in RT (mean correct incongruent minus congruent trials) were submitted to an ANOVA with session as a repeated-measures factor to examine the quantitative patterns of performance in executive function across the sessions. The main effect of session was significant, $F(9, 81) = 10.16, p < .0001$, reflecting that the executive effects decrease as the sessions progress. No other interactions were significant. In addition, it can be seen by comparing Figures 3.3.1 and 3.3.2 that the negative impact of distractors in the presence of non-spatial cues observed in Session 1 seemed to have attenuated. However, this was not statistically significant¹⁴.

For error rate, the main effects of cue condition, $F(3, 27) = 8.72, p < .001$, and target congruency, $F(2, 18) = 21.52, p < .0001$, were significant. The main effect of session was significant, $F(9, 81) = 2.02, p < .05$. The interaction between cue condition

¹⁴ A separate ANOVA was conducted with session (Session 1 and Sessions 6-10), cue condition [no alert (no cue) and alert (double and center cues)] and target congruency (congruent and incongruent) as repeated-measures factors. Although the three-way interaction was not significant, $F(1, 9) = .46$, we know from our earlier work that with sufficient power the congruency effect is increased in session 1 when the participant is alert (so long as they are not cued to attend the target). And this interaction is clearly not present after the first session in the present study, hence with sufficient power we believe that the 3-way interaction would likely be significant.

and target congruency was significant, $F(6, 54) = 5.37, p < .001$, reflecting some lack of independence among the networks. The interaction between target congruency and session was marginally significant, $F(18, 162) = 1.53, p = .0857$. No other effects were significant.

Correlational analyses

Session 1. Table 3.3.1 shows the correlations among the alerting, orienting, and executive networks. Because of the small number of participants contributing only a single session of data to these analyses it is not surprising that there were no significant correlations in the analysis of the RT and error network scores, $ps > .05$.

Sessions 1-10. Means of the 10 sessions were entered in the correlation analyses. There were no significant correlations in the analysis of the RT network scores, $ps > .05$ (Table 3.3.2). In the analysis of the error rate the positive correlation between the orienting and the executive network scores was significant; participants with greater congruency effects showed greater orienting effects. Gaining more power when all the sessions were combined, the correlation analyses in error rate¹⁵ suggest that the three networks may operate interactively. However, these results should be interpreted with caution due to the small number of participants in the analyses, the number of relationships examined, and confinement of the significant correlations to error rate.

¹⁵ Even though errors are not normally distributed, we report the results with untransformed data because the literature on inter-network correlations has more often than not analyzed them untransformed. However, we did transform the errors (arcsine-transformation) and repeat the correlation analyses. Patterns are similar except two correlations; correlation between the orienting and the executive networks with the ANT when all sessions was included, $r(8) = .54$, and the correlation between the alerting and the orienting with the ANT-I when all sessions were included, $r(8) = -0.034$, were not significant with the transformed data.

Robustness of the Network Scores

Figure 3.5.1 summarizes scores of each attentional network for RT and error rate as a function of session.

In order to examine robustness of the network scores, one sample *t*-tests were conducted on each score for each session. Despite the learning effect described above in the executive network, the tests on the RT data revealed that all the network scores were significantly different from zero in all 10 sessions, $p < .01$. These results (see Figure 3.5.1) confirm that the ANT provides a robust index of each network in RT. For error rate, the executive effects were significantly different from zero across all the sessions, $p < .05$. None of the alerting effects were significantly different from zero. The orienting effects were significantly different from zero only in one session (Session 7, $p < .05$).

Reliability of the Network Scores

First, reliability was examined by correlating the first two sessions to allow comparison with Fan et al.'s (2002) correlational analyses between Sessions 1 and 2. Then, reliability including different number of consecutive sessions was examined using a modified split-half correlation. In this permutation method¹⁶, trials were randomly split into two halves 10,000 times, a correlation was computed for each split, and reliability was the mean of the 10,000 correlations.

With RT, the correlation between Sessions 1 and 2 was significant for the executive network, and was not significant for the alerting and the orienting network (Table 3.4). These results are different from Fan et al. (2002) who reported that the

¹⁶ We thank Mike A. Lawrence for proving us with R scripts for the modified split-half correlational analyses.

correlations between Sessions 1 and 2 were significant for all the network scores. None of the correlations for error rate were significant in the current study.

Results of the modified split-half reliability analyses as a function of number of consecutive sessions included in the analysis can be seen in Figure 3.6.1¹⁷. The executive network was significantly reliable (i.e., correlated) for RT regardless of the number of the sessions included and for error rate so long as more than first three sessions were included. Reliability for the executive network increased with increasing number of sessions and reached an asymptote when more than first five and four sessions were included for RT and error rate, respectively. The alerting network was significantly reliable for RT when more than the first seven sessions were included, but not for error rate regardless of the number of the sessions included. The orienting network was significantly reliable only when all the sessions were included for RT, and was not reliable regardless of the number of the sessions included for error rate.

ANT-I

For each participant, mean correct RT after eliminating extreme values (less than 200 ms and more than 1200 ms: 1.1% of the total) and mean error rate were computed and subjected to analyses. Table 3.2 shows mean correct RT and error rate collapsed across session, and Figures 3.2.3-5 shows mean correct RT and error rate for auditory signal, and visual cue, and target congruency as a function of session

¹⁷ The same analysis was conducted for each network within each session. Reliability fluctuated across the sessions. Only the executive scores were reliable for Sessions 4, 5, and 8 in RT and for Sessions 4, 8, and 10 for error rate.

Stability and Isolability of the Network Scores

The mean correct RT and the mean error rate were submitted to ANOVAs with auditory signal (tone and no tone), visual cue (valid, invalid, and no cue), target congruency (congruent and incongruent) as repeated-measures factors [and Session (1-10) for the Sessions 1-10 analyses].

Session 1 (Figure 3.4.1). For RT, the main effects of auditory signal, $F(1, 9) = 20.69, p < .01$, visual cue, $F(2, 18) = 37.31, p < .0001$, and target congruency, $F(1, 9) = 214.80, p < .0001$, were significant. Here it can be seen that participants were fast to respond to the target in the presence of auditory signals, valid cues, and congruent distractors.

Interactions were analyzed excluding data from the no cue trials (visual cue) because the orienting network is measured by subtracting performance in the valid cued condition from that in the invalid cue condition (Callejas et al., 2005). The interaction between auditory signal and target congruency was significant, $F(1, 9) = 13.45, p < .01$, reflecting that the congruency effect (incongruent-congruent) was greater in the tone (93.2 ms) than no tone (77.4 ms) conditions¹⁸. The interaction between auditory signal and visual cue were marginally significant, $F(1, 9) = 4.35, p = .067$. The three-way interaction between auditory signal, visual cue, and congruency was significant, $F(1, 9) = 6.24, p < .05$, suggesting that the congruency effects were greater in the invalid than in the valid conditions only in the presence of the alerting signal. No other effects were significant.

¹⁸ A subsequent analysis was carried out excluding the valid and invalid visual cue conditions. This ensures that the alerting effects from auditory signal were not confounded by the alerting effects from visual cue (Callejas et al., 2005). Inconsistent with Callejas et al., there was no interaction between the auditory signal and target congruency when there was no opportunity for participants to use the visual cue to prepare for the visual target, $F(1, 9) = 1.69$. However, there was a clear interaction between the auditory signal and target congruency when the same analysis was run including all sessions (i.e., when there was more power), $F(1, 9) = 20.03, p < .01$, consistent with Callejas et al.

The interactions replicated those reported by Callejas et al. (2005) and Ishigami and Klein (2009a/Chapter 2) in which the executive network was inhibited by the alerting network (see also Posner, 1994, see Discussion for an alternative interpretation), but facilitated by the orienting network (see also Funes et al., 2007).

For error rate, the main effects of auditory signal, $F(1, 9) = 7.11, p < .05$, and target congruency, $F(1, 9) = 25.11, p < .001$, were significant. Here it can be seen that participants were more accurate in the absence of auditory signals and presence of congruent distractors. The interaction between auditory signal and congruency was significant, $F(1, 9) = 12.25, p < .01$ reflecting that the congruency effect was greater in the tone than no tone conditions¹⁹. No other effects were significant.

Sessions 1- 10 (Figure 3.4.2). Session (1-10) was included in the analyses as a repeated-measures factor. For RT, the main effect of session was not significant, $F(9, 81) = .89$. The main effects of auditory signal, $F(1, 9) = 17.44, p < .01$, visual cue, $F(2, 18) = 47.92, p < .0001$, and target congruency, $F(1, 9) = 191.99, p < .0001$, were significant. Participants were fast to respond to the target in the presence of auditory signals, valid cues, and congruent distractors. The interaction between visual cue and target congruency was significant, $F(1, 9) = 16.33, p < .01$, reflecting that the congruency effect was greater for the invalid (73.2 ms) than for the valid (55.6 ms) conditions. The interaction between auditory signal and target congruency was significant, $F(1, 9) = 10.72, p < .01$, reflecting that the congruency effect was greater for the tone (70.9 ms) than no tone (57.2 ms) conditions. It can be seen that the executive network was inhibited by the alerting

¹⁹ A subsequent analysis was carried out excluding the valid and invalid visual cue conditions as with the RT analyses. The interaction was significant, $F(1,9) = 7.88, p < 0.01$

network, but facilitated by the orienting network. The interaction between visual cue and session, $F(9, 81) = 3.68, p < .001$, and between target congruency and session, $F(9, 81) = 7.82, p < .0001$, were significant. Consistent with the ANT, it can be seen from Figure 3.2.5 that the learning effect in the executive network was due mainly to an improvement in the incongruent condition. As with the ANT, a different ANOVA was run to examine the quantitative patterns of performance in executive function across the sessions. The mean executive network scores in RT (mean correct incongruent minus congruent trials) were submitted to an ANOVA with session as a repeated-measures factor. The main effect of session was significant, $F(9, 81) = 6.81, p < .0001$, reflecting that the executive effects decrease as the sessions progress. Important, but less obvious was the learning effect in the orienting network, that was due mainly to an improvement in the invalid condition seen in Figure 3.2.4. As in the executive effects, the mean orienting network scores in RT (mean correct invalid minus valid trials) was submitted to an ANOVA with session as a repeated-measures factor. The main effect of session was significant, $F(9, 81) = 3.51, p < .01$, reflecting that the orienting effects decrease as the sessions progress²⁰. The interaction between auditory signal and visual cue was marginally significant, $F(1, 9) = 3.38, p = .099$. No other effects were significant.

For error rate, the main effects of visual cue, $F(2, 18) = 17.65, p < .0001$, and target congruency, $F(1, 9) = 32.30, p < .001$, were significant. Here it can be seen that participants were more accurate in the presence of valid cues and congruent distractors.

²⁰ As reported above, the main effect of session on RT was not significant. Yet, the main effects of the orienting and executive networks were significant. Figures 3.2.4, and 3.2.5 show larger RT reduction from Session 1 to Session 2. Separate ANOVAs were run with session (Sessions 1-2 for the first analysis and Sessions 2-10 for the second analysis) as a repeated-measures factor. The main effects of session were not significant. A visual inspection of RT across sessions suggests that there is a non-significant trend of RT reduction.

The main effect of session was significant, $F(9, 81) = 2.54, p < .05$, reflecting that performance fluctuated across the sessions. The interaction between visual cue and congruency was significant, $F(1, 9) = 9.87, p < .05$; congruency effects were greater for the invalid than for the valid conditions. The interaction between target congruency and session was significant, $F(9, 81) = 2.26, p < .05$. The interaction between auditory signal and session was marginally significant, $F(9, 81) = 1.73, p = .096$. The four-way interaction between auditory signal, visual cue, target congruency, and session was significant, $F(9, 81) = 2.39, p < .05$. No other interactions were significant.

*Correlational analyses*²¹

Sessions 1: There were no significant correlations in the network scores in RT and error rate (Table 3.3.1).

Sessions 1-10: There were no significant correlations in the network scores in RT (Table 3.3.2). In error rate, the positive correlation between the alerting and the orienting network scores was significant; participants with greater orienting effects showed greater alerting effects.

Robustness of the Network Scores

Figure 3.5.2 summarizes scores of each attentional network for RT and error rate as a function of session.

Despite the learning effects described in the orienting and executive networks, one sample *t*-tests on the RT data revealed that all the networks were significantly

²¹ The alerting network scores in the correlation analyses were calculated including all trials. As with the ANOVA analyses above, a subsequent analysis was carried out excluding the valid and invalid visual cue conditions. Significance of the correlations involving the alerting network was similar to those including all trials, except the correlation between the alerting and the orienting network. This correlation was not significant when only the no cue condition was included. Only the results using all trials are reported in Tables 3.3.1 and 3.3.2.

different from zero across all ten sessions, $ps < .01$. For error rate, the executive effects were significantly different from zero across the 10 sessions. These results can be found in Figure 3.5.2²². The alerting effects and the orienting effects were significantly different from zero for two (Session 1 and 9, $ps < .05$) and six sessions (Sessions 1, 2, 3, 4, 5, and 9, $ps < .05$), respectively.

Reliability of the Network Scores

With RT, the correlation between Sessions 1 and 2 was significant for the alerting and the orienting networks (Table 3.4). The correlation was not significant for the executive network. None of the correlations for error rate were significant.

Results of the modified split-half reliability analyses as a function of number of consecutive sessions included in the analysis can be seen in Figure 3.6.2²³. The alerting network was significantly reliable for RT regardless of the number of sessions included and for error rate when more than first three sessions were included. The reliabilities seemed to have increased with increasing number of sessions and reached asymptotes when the first seven and three sessions were included for RT and error rate, respectively.

²² An interesting feature seems to be that the alerting effects (in both ANT and the ANT-I, but perhaps more clearly in the ANT-I) reverses with practice in error rate; whereas more errors were made in the first session in the condition with greater alertness, fewer error were made in later sessions under alertness [see Ishigami & Klein, (2009a/Chapter 2) for the clear presence of the speed-accuracy tradeoff when the ANT and the ANT-I are tested once with 100 participants each.]. Speed-accuracy tradeoffs suggested by Posner and colleagues (Posner, Klein, Summers & Buggie, 1973; Posner, 1975 & 1978) due to alertness (phasic alertness speeds the time when information accumulating about a signal is used to generate a response without affecting the quality of the accumulating information) may be present only early in practice. After one session, the participants may have learned how to make use of warning signals without trading speed for accuracy. It is possible that the participants learned a contingency between the warning signal and the cue with a fixed SOA (Correa, Lupianez, & Tudela, 2005; Lawrence, Klein, & LoLordo, 2008), resulting in improvements in performance.

²³ The same analysis was conducted for each network within each session. Reliability fluctuated across the sessions. The orienting network scores were not reliable for any of the sessions both in RT and error rate. The alerting network scores were reliable for all the sessions in RT but not in error rate. The executive network scores were reliable only for Sessions 2, 4, and 5 in RT and for Sessions 3 and 4 in error rate.

The executive network was significantly reliable when more than first two sessions and three sessions were included reaching asymptote with the inclusion of the first seven and four sessions, for RT and error rate, respectively. The orienting network was significantly reliable for RT when more than first three sessions were included, but not for error rate regardless of the number of the sessions included. The reliability of RT seemed to increase with increasing number of sessions and reached an asymptote when the first five sessions were included. In addition, comparing correlations between the first two sessions and reliabilities when all the ten sessions were included suggests better reliability when more data were included (Table 3.4).

Correlation Between the Network Scores Generated by the Two Tests

Although the ANT and the ANT-I were written in different programs and run with different types of computer (see the method section above) and although alerting and orienting are measured somewhat differently (see Introduction) by the two tests, in this section we will compare the magnitudes of the network scores measured by the two tests and we will explore the correlation between corresponding scores (Table 3.5). For RT, the alerting network scores generated by the ANT and ANT-I were not significantly different. The correlation between these scores was significant. The difference between the orienting networks measured with the two tests was not significant. The correlation between these scores was significant. The executive network measured with the two tests was significantly different. The correlations between these scores were significant. For error rate, the alerting and orienting network scores measured with the two tests were not significantly different. The correlations were not significant for these networks. The

difference between the executive networks measured with the two tests was not significant. The correlation between these scores was significant.

Discussion

The present experiment was conducted to examine the stability, isolability, robustness, and reliability of the measures of attention network (alerting, orienting, and executive) derived from two versions of the ANT over repeated testing. We observed learning effects of executive function both in the ANT and the ANT-I and learning effects of orienting in the ANT-I (Figures 3.5.1 and 3.5.2). Despite these learning effects, both the ANT and the ANT-I produced a robust index of each attention network even after the 10 sessions of each test. There was some lack of independence among the networks in both tests. Overall, the reliability of the network scores was found to be greater with the ANT-I than the ANT. In addition, examination of the data shows that the participants were: 1) quick to respond and accurate when given peripheral cue (spatial in the ANT and valid in the ANT-I) whether it was 100% informative (ANT) or uninformative (ANT-I) and 2) slow and inaccurate in the presence of distracting incongruent information (Figures 3.2.2 and 3.2.5) across the 10 sessions.

The learning effects for executive function in RT in the ANT and ANT-I are clearly observed. The executive network is defined by the incongruent and congruent conditions. A close examination of Figures 3.2.2 and 3.2.5 shows that decreased executive effects across the sessions are due mainly to decreased RT in the incongruent condition. Thus, as they practice the task (across sessions) the participants learned how to ignore the irrelevant flanking arrows. In addition, learning effects for orienting in the

ANT-I were observed. The orienting effects decreased as the sessions progressed. The orienting network in the ANT-I is defined by the invalid and valid conditions. A close examination of Figure 3.2.4 shows that the learning curve for the invalid condition is steeper than for the valid condition in earlier sessions. The participants seemed to learn to disengage from the uninformative cues more efficiently.

The learning effects with orienting were observed only with the ANT-I. The difference between the ANT and the ANT-I may be due to the different components involved in the orienting network for the two tests. In the ANT, the peripheral cue is 100% valid. Thus, it is in the participants' advantage to pay attention to this cue. On the other hand, in the ANT-I, the peripheral cue is not informative. Thus, it is of the participants' advantage to ignore the cue. The participants learned how to ignore irrelevant information in the ANT-I - similar pattern observed in the executive network. The reliability of the network scores is generally greater with the ANT-I than with the ANT. The reliability of all the network scores measured with the both tests seem to have reached asymptotes after around Session 5, especially with RT.

Lastly, our data largely replicate previous studies (Callejas et al., 2004; Fan et al., 2002) and show that the three attention networks do not operate independently in all situations. The executive network was inhibited by the alerting network (see also Posner, 1994), but facilitated by the orienting network (see also Funes et al., 2007). This causal interpretation is possible because the alerting signal precedes the target. However, it is also possible that phasic alertness speeds the time when information accumulating about a signal is used to generate response affecting the quality of the accumulating information

in the presence of congruent information, but not in the presence of the incongruent information (e.g., Fernandez-Duque & Black, 2006; Posner, 1978). Whether the orienting network is facilitated by the alerting network when SOA is long (i.e., 500 ms) was not as clear as in previous studies (Callejas et al., 2002; Callejas, Lupianez, & Tudela, 2004), that found the interaction only with a short SOA (i.e., 100 ms). It is possible that alerting only increases the speed of responding and not the efficiency of information processing (Posner, 1975).

Conclusion

Both ANTs are useful tools to measure attention components, namely alerting, orienting, and executive functions, within one session, which takes less than 30 minutes. The current study shows that scores of these attention components remain robust even after 10 sessions. This enables either ANT to be used in applications that require repeated testing. It is important to note, however, that executive control scores with both ANTs, and orienting with the ANT-I decrease with practice. Therefore, an untreated control group might be warranted in some designs. While the network scores are robust against practice, their reliability is generally lower than is ideal for many purposes. Importantly, the scores measured with the ANT-I were generally more reliable than with the ANT. The network scores generated by the two tests were found to be related to each other. As we expected the executive effects, which are measured by the two tests using essentially the same conflicting and congruent arrows, were highly related. Phasic alertness, in contrast, is induced by different modalities in these tests: visual in the ANT and auditory in the ANT-I. The scores from the two tests are highly related even though auditory

signals may generate alertness more automatically than visual signals (Fernandez-Duque & Posner, 1997). The orienting component of attention is measured quite differently in the two tests; whereas the 100% valid peripheral cue used in the ANT allows both endogenous and exogenous control to operate, with the uninformative peripheral cues of the ANT-I orienting depends on the degree to which the cue captures attention exogenously. Despite this difference, the scores from the two tests were significantly correlated. One thing the two tests have in common is the use of peripheral cues. Perhaps, the significant correlation is related to the degree to which a peripheral cue captures attention whether or not it is informative.

Table 3.1

Conditions and their levels in the ANT and the ANT-I.

	ANT	ANT-I
Auditory signal	NA	Tone
		No tone
Cue condition (ANT) Visual cue (ANT-I)	No cue	No cue
	Center cue	Valid
	Double cue	
	Spatial cue	Invalid
Target congruency	Neutral	Congruent
	Congruent	
	Incongruent	Incongruent

Subtractions for each network

	ANT	ANT-I
Alerting	No cue - Double cue	No tone – Tone
Orienting	Center cue - Spatial cue	Invalid – Valid
Executive	Incongruent - Congruent	Incongruent - Congruent

Table 3.2

Mean RT (ms) and error rate (proportion incorrect) (between parenthesis) for the ANT and the ANT-I.

ANT

	No cue	Center	Double	Spatial
Congruent	582 (.008)	543 (.008)	535 (.004)	524 (.007)
Incongruent	654 (.080)	628 (.075)	620 (.067)	598 (.045)
Neutral	572 (.013)	509 (.016)	495 (.009)	482 (.010)

ANT-I

	Tone			No tone		
	Valid	Invalid	No cue	Valid	Invalid	No cue
Congruent	434 (.003)	460 (.009)	444 (.006)	479 (.007)	498 (.009)	519 (.008)
Incongruent	497 (.040)	541 (.070)	516 (.061)	527 (.048)	564 (.075)	569 (.050)

Table 3.3.1

Correlations between attentional networks in the ANT in Session 1.

RT	Alerting	Orienting	Error Rate	Alerting	Orienting
Orienting	-0.13		Orienting	-0.38	
Executive	0.14	0.11	Executive	0.25	0.54

Correlations between attentional networks in the ANT-I in Session 1.

RT	Alerting	Orienting	Error Rate	Alerting	Orienting
Orienting	0.16		Orienting	-0.38	
Executive	-0.19	0.34	Executive	-0.60	0.36

Table 3.3.2

Correlations between attentional networks in the ANT in Sessions 1-10.

RT	Alerting	Orienting	Error Rate	Alerting	Orienting
Orienting	0.55		Orienting	0.59	
Executive	-0.24	-0.16	Executive	0.58	0.88**

Correlations between attentional networks in the ANT-I in Sessions 1-10.

RT	Alerting	Orienting	Error Rate	Alerting	Orienting
Orienting	0.03		Orienting	0.68*	
Executive	-0.40	0.34	Executive	0.09	0.41

* $p < .05$

** $p < .001$

Table 3.4

Reliability of the three attentional networks from correlational analyses between Sessions 1 and 2 (Fan et al., 2002 & current study) and from a variation of split-half correlational analyses including all the sessions (current study).

	Network	Fan et al.	Sessions 1-2	Sessions 1-10	
ANT	RT	Alerting	0.52**	-0.02	0.80**
		Orienting	0.61**	0.57	0.65*
		Executive	0.77**	0.86**	0.93**
	Error	Alerting	N/A	0.20	-0.02
		Orienting	N/A	0.42	0.32
		Executive	N/A	0.45	0.93**
ANT-I	RT	Alerting	N/A	0.64*	0.98**
		Orienting	N/A	0.77**	0.81**
		Executive	N/A	0.48	0.89**
	Error	Alerting	N/A	0.28	0.70*
		Orienting	N/A	0.43	0.02
		Executive	N/A	0.63	0.92**

* $p < .05$

** $p < .01$

Table 3.5

Network scores generated by the ANT and the ANT-I, their difference, and the correlation between the scores from the two different versions of the ANT.

	Network	ANT	ANT-I	<i>t</i> (9)	<i>r</i> (9)
RT	Alerting	53.1	48.8	1.43	0.86**
	Orienting	24.2	30.6	-2.05	0.69*
	Executive	78.6	63.1	3.58**	0.86**
Error	Alerting	0.007	0.001	1.24	0.11
	Orienting	0.012	0.016	-1.02	0.24
	Executive	0.060	0.050	1.94	0.941**

* $p < .05$

** $p < .01$

Figure 3.1.1

Experimental procedure of the ANT (Fan et al., 2002). (I) the four cue conditions. (II) the six target stimuli used in the present experiment. and (III) an example of the procedure; a spatial cue is presented followed by a target (central) arrow.

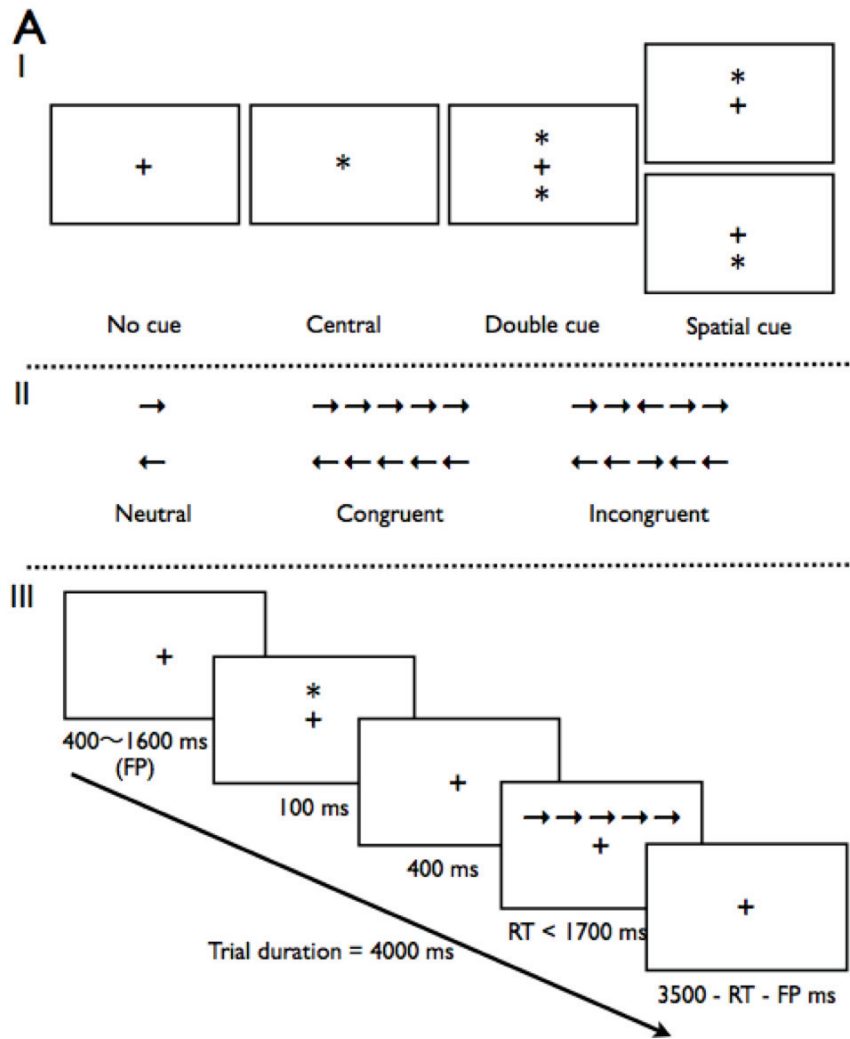


Figure 3.1.2

Experimental procedure of the ANT-I (Callejas et al., 2005). An example of the procedure; an auditory tone is presented, followed by a valid cue, and a target (central) arrow flanked by congruent arrows.

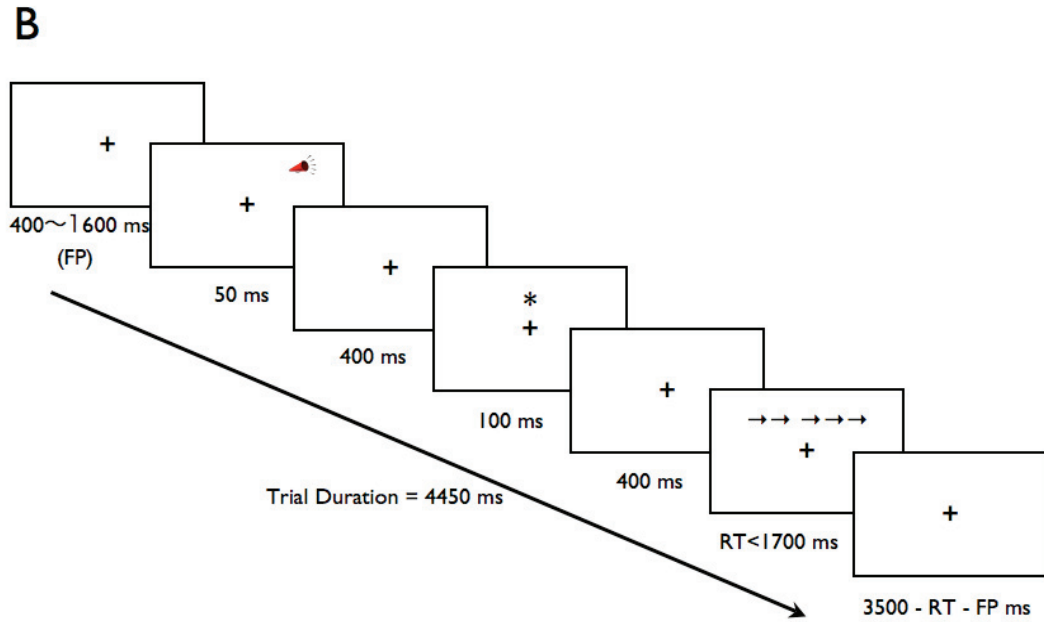


Figure 3.2.1

Mean correct RT and error rate on the ANT as a function of cue condition and session.

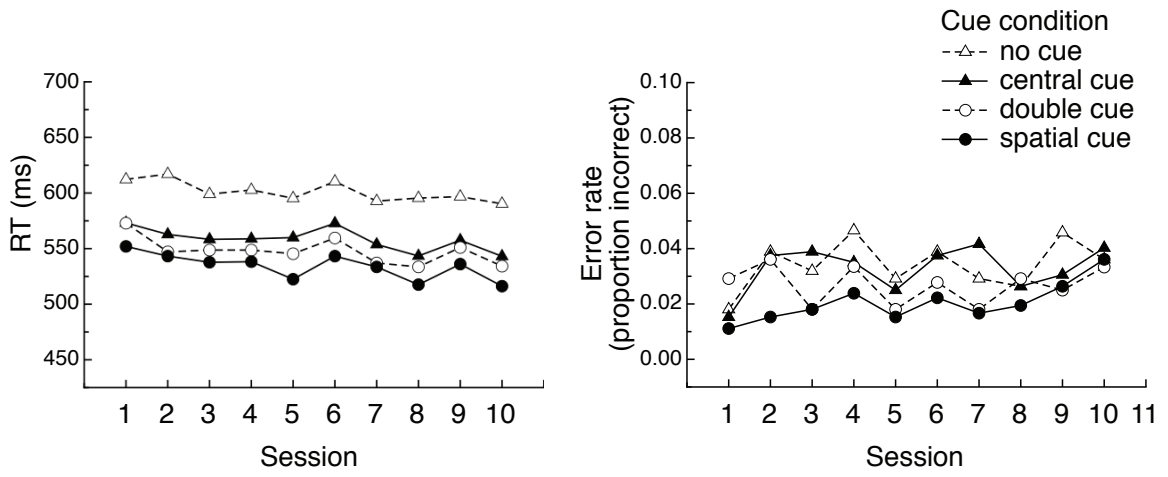


Figure 3.2.2

Mean correct RT and error rate on the ANT as a function of target congruency and session.

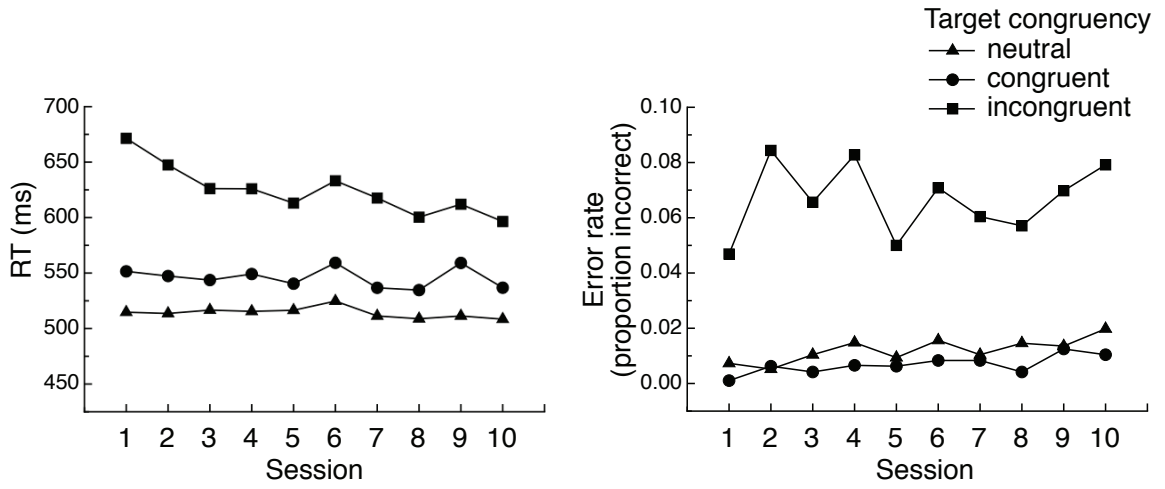


Figure 3.2.3

Mean correct RT and error rate on the ANT-I as a function of auditory signal and session.

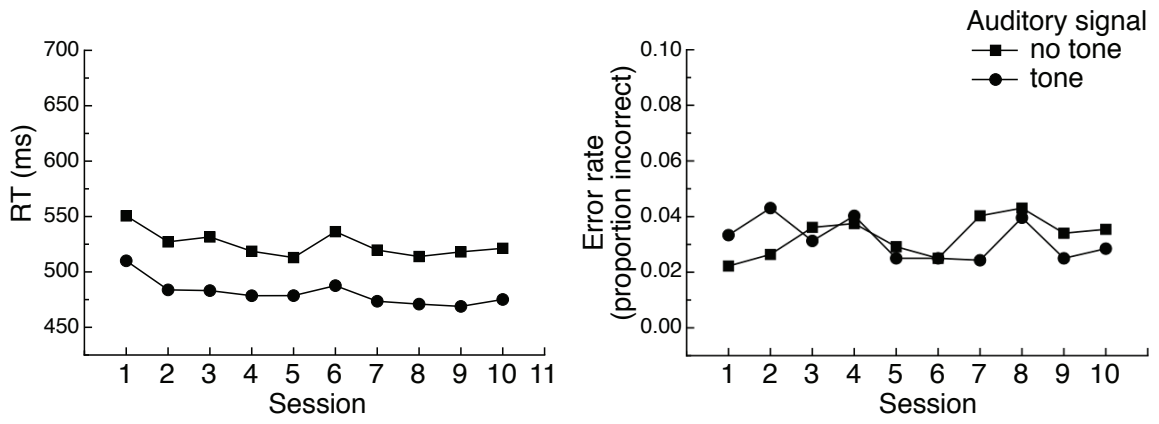


Figure 3.2.4

Mean correct RT and error rate on the ANT-I as a function of visual cue and session.

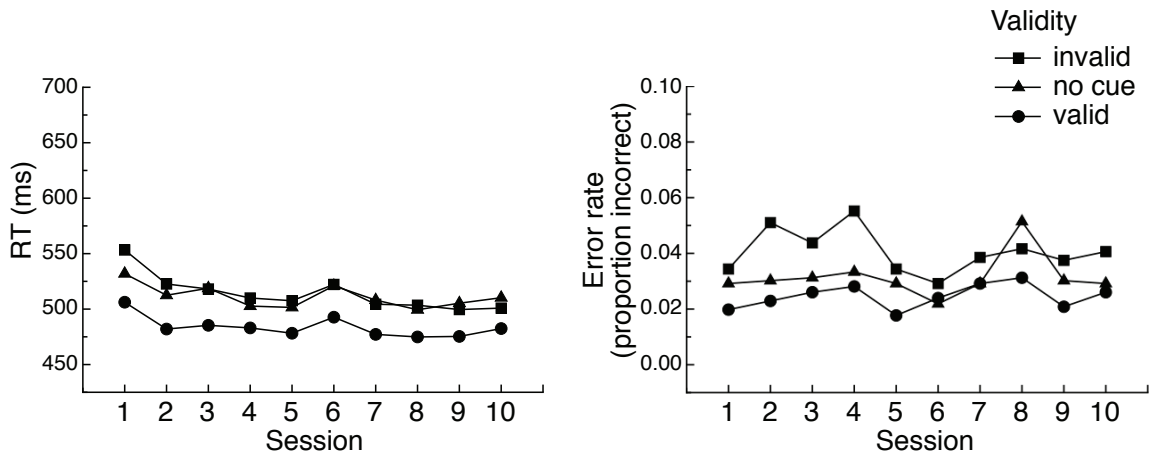


Figure 3.2.5

Mean correct RT and error rate on the ANT-I as a function of target congruency and session.

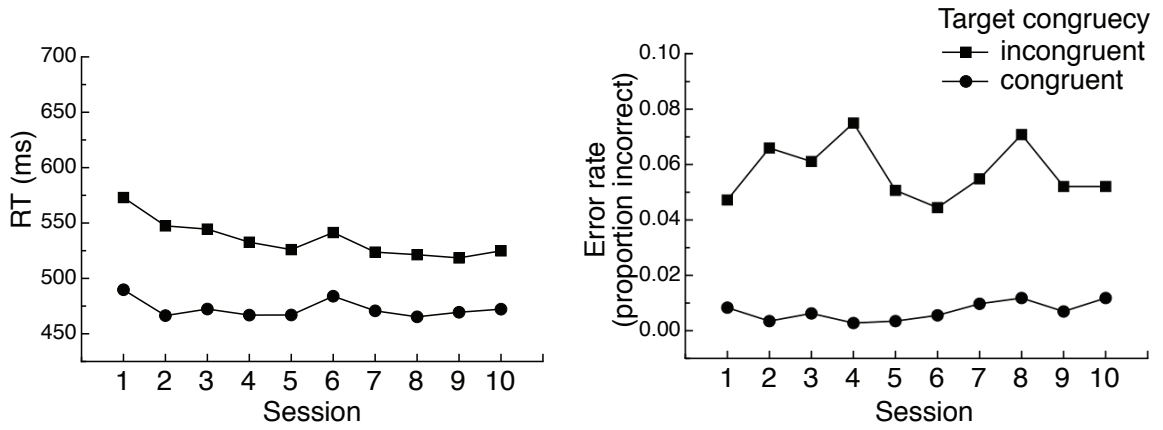


Figure 3.3.1

Mean correct RT and error rate on the ANT for Session 1 as a function of cue condition and target congruency.

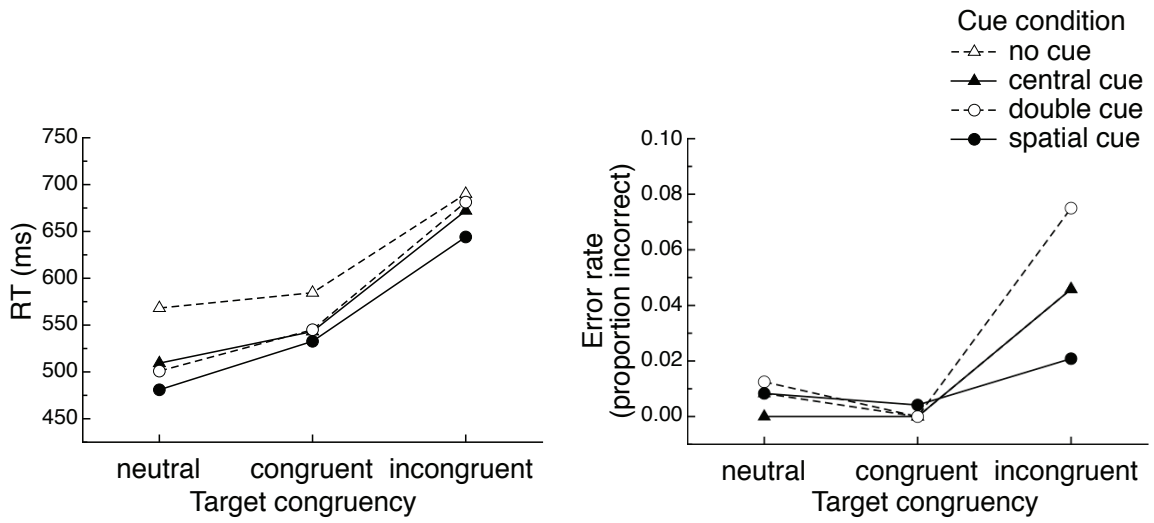


Figure 3.3.2

Mean correct RT and error rate on the ANT for Sessions 1-10 as a function of cue condition and target congruency.

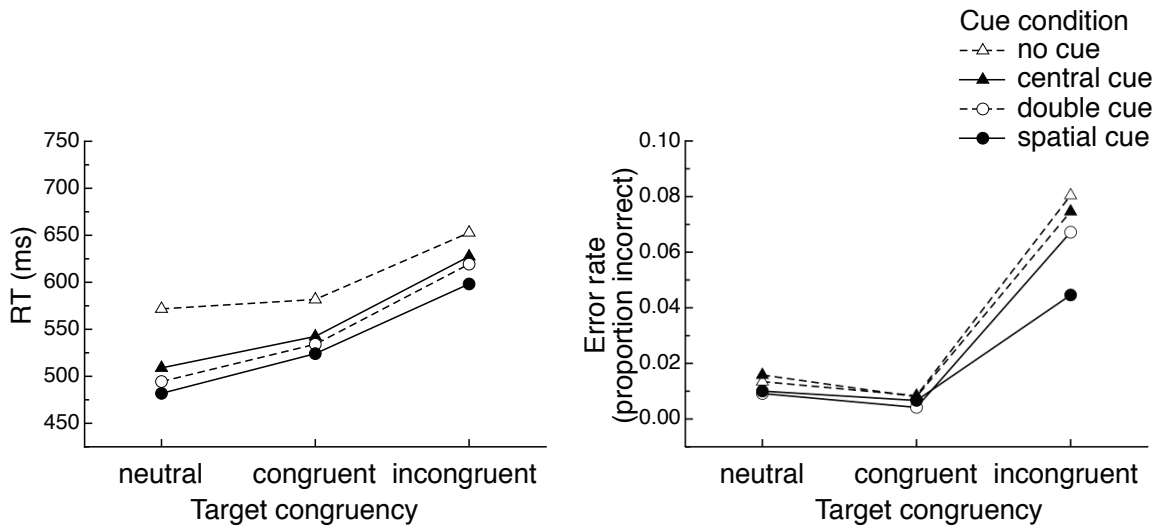


Figure 3.4.1

Mean correct RT and error rate for Session 1 on the ANT-I as a function of target congruency and tone & validity.

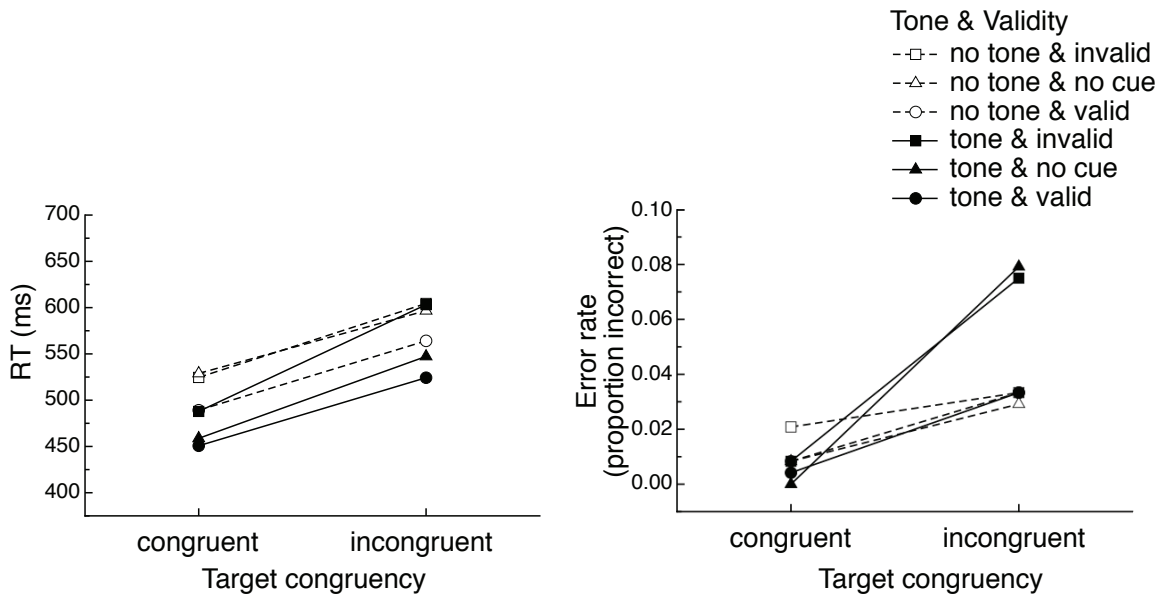


Figure 3.4.2

Mean correct RT and error rate for Sessions 1-10 on the ANT-I as a function of target congruency and tone & validity.

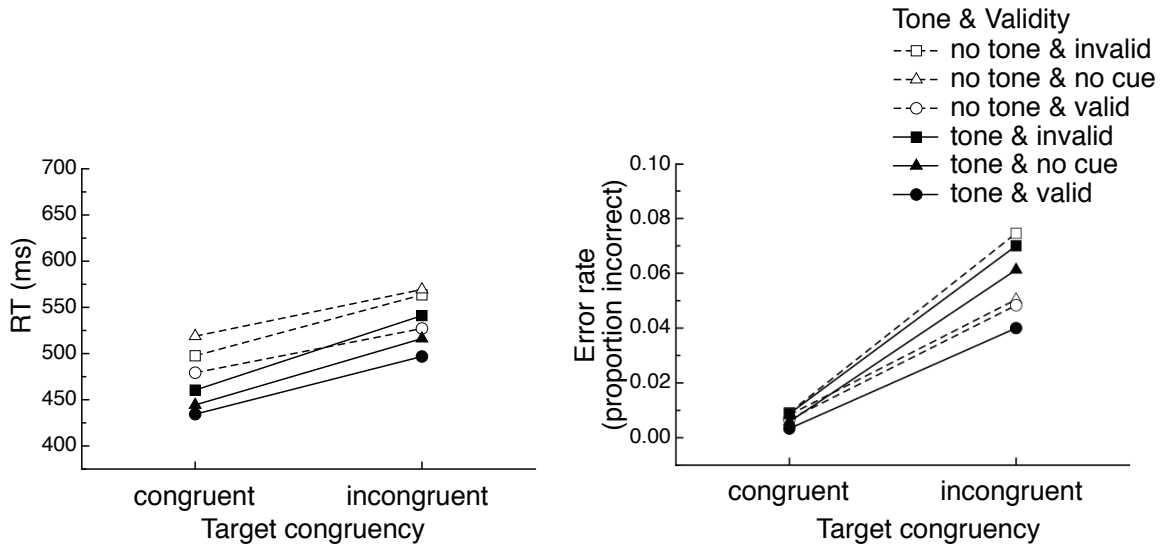


Figure 3.5.1

Mean of each network scores (i.e., difference scores) in RT (top panels) and error rate (bottom panels) for alerting (no cue - double cue), orienting (center cue - spatial cue), and executive (incongruent - congruent) networks in the ANT. The error bars are 95 percent confidence intervals, which can be used to compare scores against zero. Free standing error bars at the top right of each figure are LSDs to compare scores across the sessions.

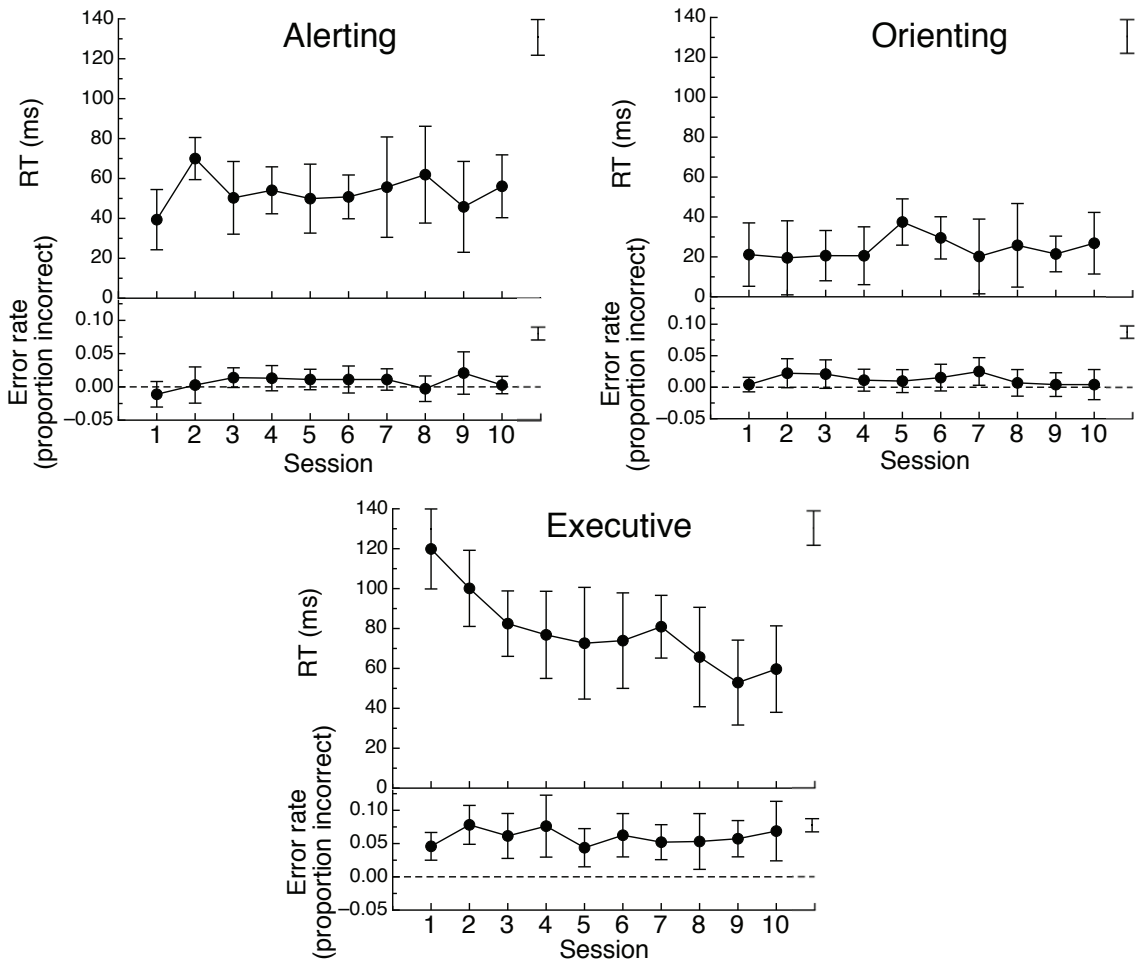


Figure 3.5.2

Mean of each network scores (i.e., difference scores) in RT (top panel) and error rate (bottom panes) for alerting (no tone - tone), orienting (invalid - valid), and executive (incongruent - congruent) networks in the ANT-I. The error bars are 95 percent confidence intervals, which can be used to compare scores against zero. Free standing error bars at the top right of each figure are LSDs to compare scores across the sessions.

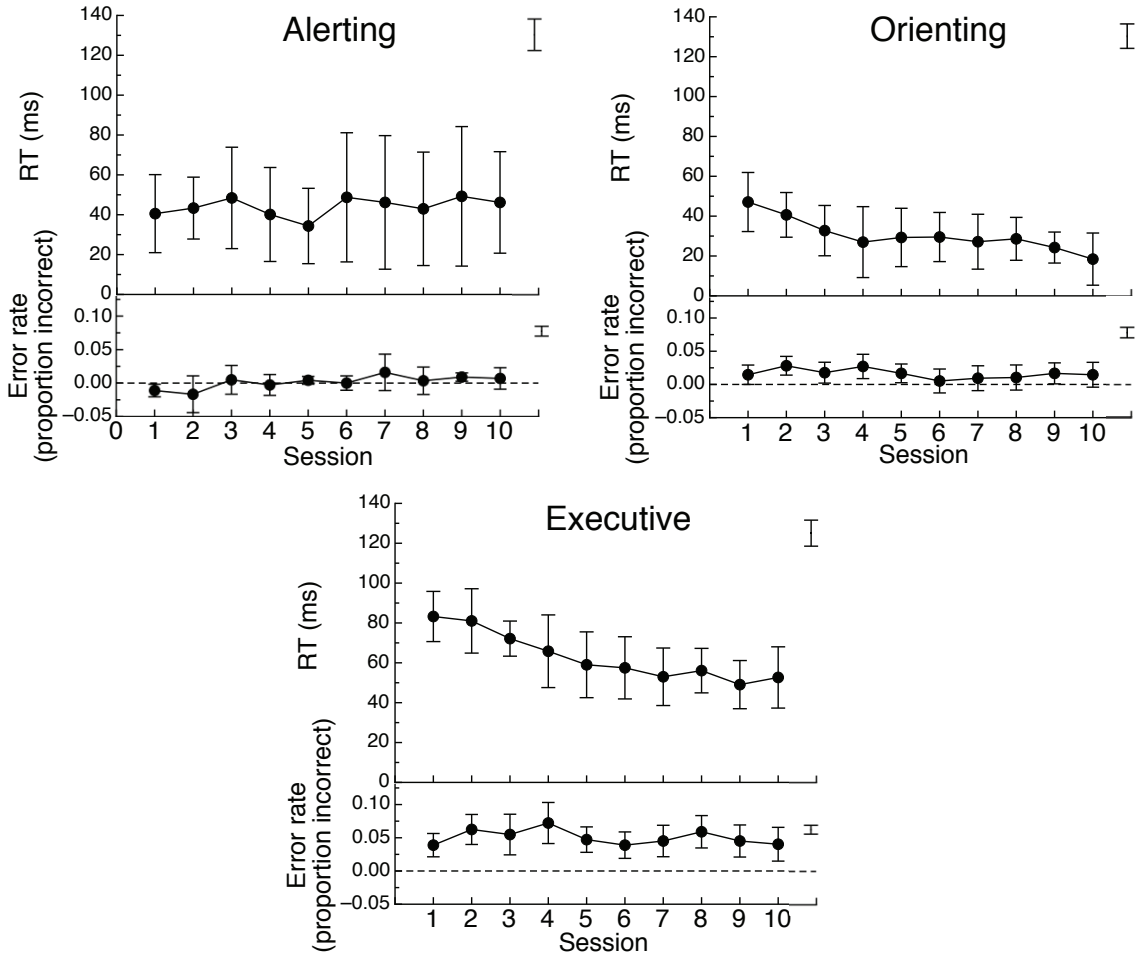


Figure 3.6.1

Reliability of each network scores as a function of number of consecutive sessions included in the analysis (always beginning with Session 1) in the ANT. Reliability was examined using a modified split-half correlation (permutation approach). With a permutation approach, trials were randomly split into two halves 10,000 times, a correlation was computed for each split, and reliability was the mean of the 10,000 correlations. Correlation is significant at the .05 level if $r \geq .64$ and significant at the .01 level if $r \geq .77$ given $N = 10$.

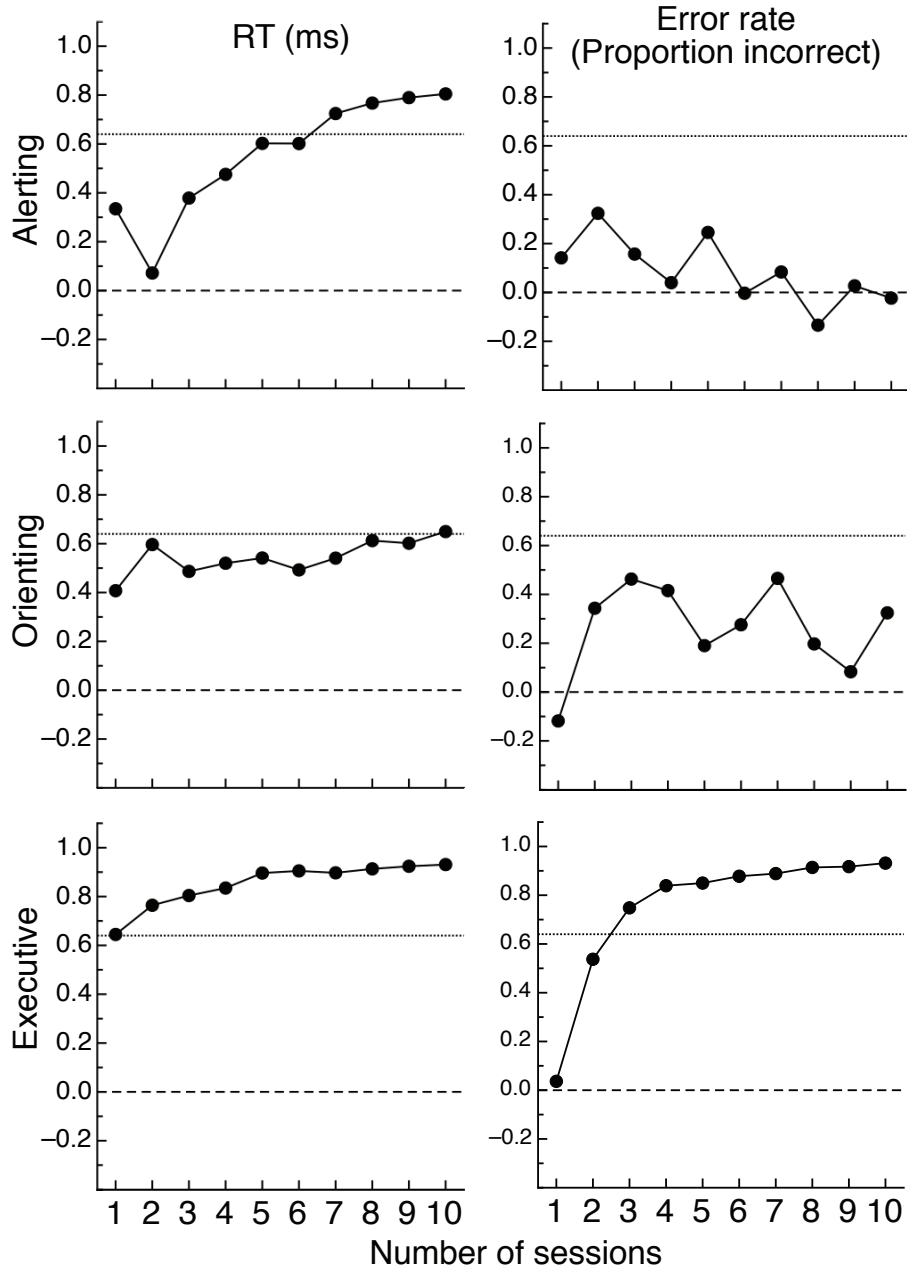
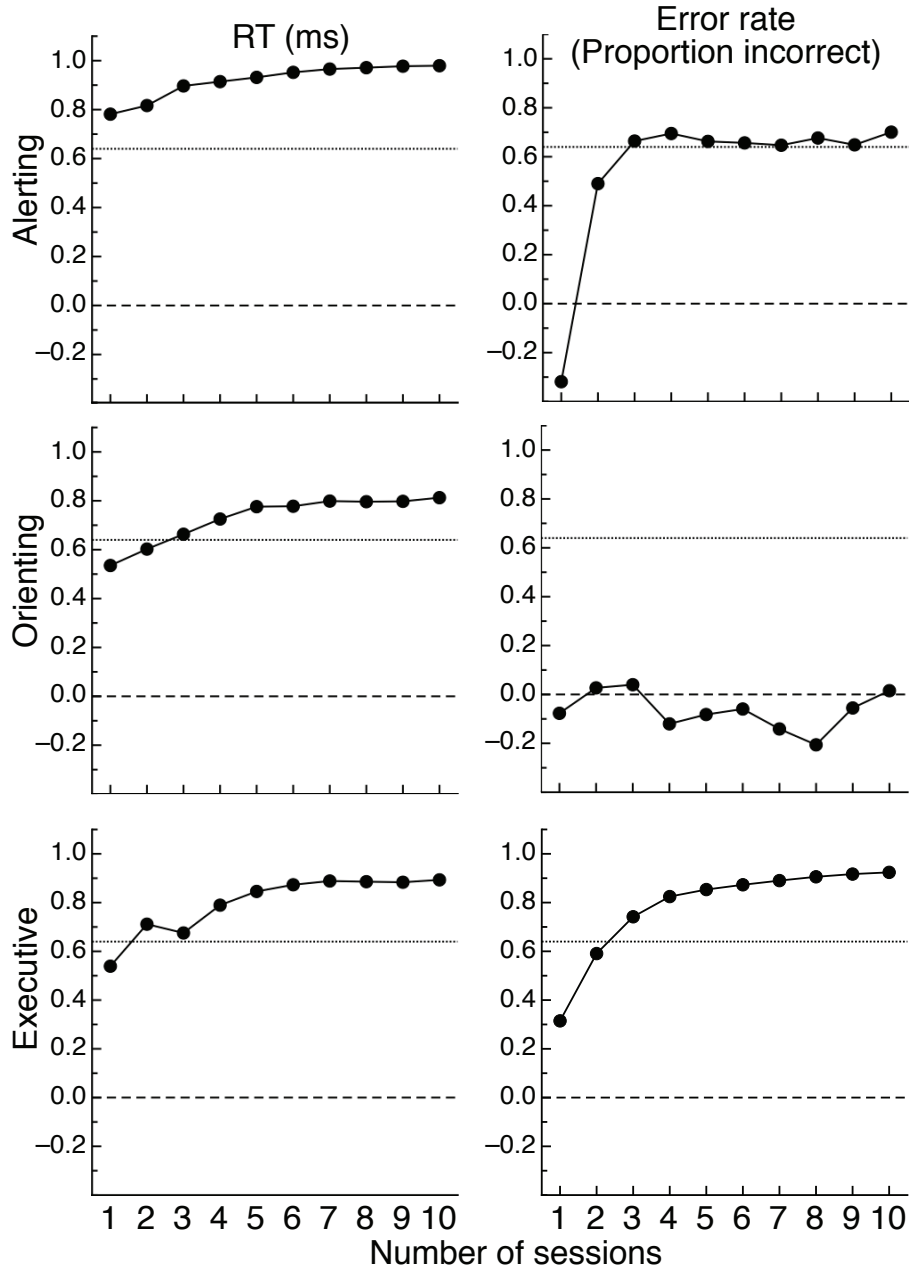


Figure 3.6.2

Reliability of each network scores as a function of number of consecutive sessions included in the analysis (always beginning with Session 1) in the ANT-I. Reliability was examined using a modified split-half correlation (permutation approach). With a permutation approach, trials were randomly split into two halves 10,000 times, a correlation was computed for each split, and reliability was the mean of the 10,000 correlations. Correlation is significant at the .05 level if $r \geq .64$ and significant at the .01 level if $r \geq .77$ given $N = 10$.



CHAPTER 4:
REPEATED MEASUREMENT OF THE COMPONENTS OF ATTENTION OF
OLDER ADULTS
USING THE TWO VERSIONS OF THE ATTENTION NETWORK TEST (ANT):
STABILITY, ISOLABILITY, ROBUSTNESS, AND RELIABILITY

The manuscript based on this study is presented below. It was published (abstract) in 2009 with *Canadian Journal of Experimental Psychology-Revue Canadienne De Psychologie Experimentale*, 63(4), 344, and it was submitted for publication (manuscript) to *Frontiers in Aging and Neuroscience*. Co-author for this manuscript is Dr. Raymond Klein.

Abstract

Ishigami and Klein (2010/Chapter 3) showed that scores of the three attention networks (alerting, orienting, and executive control) measured with the two versions of the Attention Network Test (ANT: Fan et al., 2002, Callejas et al., 2005) were robust over 10 sessions of repeated testing even though practice effects were consistently observed especially in the executive network when young adults were tested. The current study replicated their method to examine robustness, stability, reliability and isolability of the networks scores when older adults were tested with these ANTs. Ten test sessions, each containing two versions of the ANT were administered to 10 older adults. Participants were asked to indicate the direction of a target arrow, flanked by distractors, presented either above or below the fixation following auditory signals or/and visual cue. Network scores were calculated using orthogonal subtractions of performance in selected conditions. All network scores remained highly significant even after nine previous sessions despite some practice effects in the executive and the alerting networks. Some lack of independence among the networks was found. The relatively poor reliability of network scores with one session of data rises to respectable levels as more data is added. In comparison with our previous findings with young adults, older adults may put more effort into following instructions. Differences between young and older adults in the network scores and in the network interactions may have more to do with strategies that change with age than with basic changes in attentional functions.

Introduction

Attention has been of interest in the literature on aging because aging in humans includes a multidimensional process of attentional changes. However, the precise empirical relationship between aging and attention remains somewhat inconclusive (for reviews, see Groth & Allen, 2000; Kok, 1999, 2000; Rogers, 2000). We will begin by briefly reviewing how aging effects the three components of attention (alerting, orienting, and executive control) proposed by Posner and Petersen (1990).

Alerting

Alertness can be subdivided into phasic and tonic alertness. Tonic alertness or sustained attention is a state of general wakefulness or vigilance and refers to one's ability to sustain attention over a period of time. Phasic alertness involves a change in mental state as well as some changes in physiological state following a presentation of a warning signal, and prepares the individual for fast reactions (Posner, 1978). Alerting, as discussed in the context of the Attention Network Test (Callejas, Lupianez, Funes, & Tudela, 2005; Fan, McCandliss, Sommer, Raz, & Posner, 2002) (see below), is phasic alertness. Phasic alertness is typically examined by comparing performance following warning signals and performance without such warning signals. Previous studies show that aging had relatively little effect on phasic alertness (e.g., Nebes & Brady, 1993; Rabbitt, 1984; Tales, Muir, Bayer, Jones, & Snowden, 2002a) when the stimulus onset asynchrony (SOA) between the warning signal and the target was fixed. However, when SOA was varied within a block, Festa-Martino, Ott, and Heindel (2004) reported that older adults showed smaller alerting effects than younger adults.

Orienting

Orienting, which can be controlled by primarily exogenous or endogenous means, involves selective allocation of attention to a source of signals in space (Posner, 1980). The standard paradigm for studying orienting is the Posner spatial cueing task (1980). Benefits and costs in performance associated with valid and invalid cues or cueing effects associated with these cues are examined. Previous studies show that aging may have relatively little effect on exogenous or automatic orienting to peripheral cues regardless of their predictability regarding the targets (Brodeur & Enns, 1997; Festa-Martino et al., 2004; Greenwood, Parasuraman, & Haxby, 1993; Hartley, Kieley, & Slabach, 1990, E3, Tales, Muir, Bayer, & Snowden, 2002b; Waszak, Li, & Hommel, 2010)²⁴. However, results regarding endogenous or voluntary orienting are mixed in the literature²⁵. Some studies reported that the older adults showed larger costs/benefits or cueing effects (Folk & Hoyer, 1992, E1; Greenwood et al., 1993; Hartley et al., 1990, E2; Nissen & Corkin, 1985). Other studies reported that these effects were similar between the older adults and the young adults (Brodeur & Enns, 1997; Hartley et al., 1990, E3; Lincourt, Folk, & Hoyer, 1997; Tales et al., 2002b)

Executive control

Executive attention involves conflict resolution and control over decision-making, error detection, and habitual response inhibition (Norman & Shallice, 1986). One of the

²⁴ Although these studies report statistical non-significance between the young and the older adults, the older adults in these studies (except Tales et al., (2002b) when the task was identification) show numerically greater orienting effects.

²⁵ A comprehensive picture of the patterns of endogenous orienting is difficult to draw; task (identification and detection), type of endogenous cue (central arrow and informative peripheral stimulus), and SOA (50 - 3000 ms) vary across the studies. It appears, however, that studies showing age differences in orienting effects typically use longer SOAs.

typical ‘interference’ paradigms used to examine conflict resolution is the flanker task (Eriksen & Eriksen, 1974). In this task, filtering out irrelevant information is required to perform the task efficiently (e.g., ignoring flanking distractors in the flanker task). Whereas congruency effects (incongruent distractor trials minus congruent distractor trials) for young and older adults are generally similar when ignoring irrelevant letter identities was required (e.g., Kramer, Humphrey, Larish, Logan, & Strayer, 1994; Madden & Gottlob, 1997), Waszak et al. (2010) found greater congruency effects for older adults when ignoring irrelevant colors was required. Further, Zeef, Sonke, Kok, Buiten, and Kenemans (1996) found greater congruency effects for older adults, but only when the smallest distance between targets and distractors was tested. D’Aloisio and Klein (1990) also found a similar pattern in their analysis of reaction time (RT). When D’Aloisio and Klein took accuracy into account, however, they reported that the difference between the young and the old adults diminished.

Typically, the different components of attention have been examined using different paradigms. Thus, three different experiments may be conducted to examine these attention components within the same individuals. In that case, it is not possible to examine how these components interact. The Attention Network Test (ANT), however, enables us to examine these attention components all at once and to examine how they interact. The original Attention Network Test (ANT) was developed by Fan et al. (2002) to measure three attention networks: alerting, orienting, and executive control. Later, the Attention Network Test – Interaction (ANT-I) was developed by Callejas et al. (2005) to

improve the ANT (see Ishigami & Klein, 2009a/Chapter 2, 2010/Chapter 3, for detailed methods and differences between the ANT and the ANT-I).

Essentially, the ANT (and the ANT-I) is a combination of the Posner spatial cueing task (1980) and the Eriksen flanker task (1974). On each trial, different types of warning cues precede a central target arrow, pointing either left or right, that is often flanked by distracting arrows (Figures 4.1.1 and 4.1.2). The participants' task is to indicate the direction of the target arrow as quickly and accurately as possible. Specific subtraction scores are used to measure the efficiency of three different attention networks (Table 4.1).

Studies of aging using the ANTs are limited. Jennings, Dagenbach, Engle, and Funke (2007) examined age effects on the alerting, orienting, and executive networks. The ANT was administered to 63 older adults and 60 young adults. They found an interaction between cue condition (center cue, double cue, spatial cue, and no cue) and target congruency (congruent, incongruent, and neutral) (see also Fan et al., 2002; Ishigami & Klein, 2009a/Chapter 2, 2010/Chapter 3). The interactions between age and alerting (including the double cue and the no cue conditions) and between age and executive control (including congruent and incongruent conditions) were significant, reflecting that the older adults showed smaller alerting effects and greater executive effects than the young adults. However, when they analyzed the age-related effects based on transformed scores²⁶, only the interaction between age and alerting remained significant.

²⁶ Although the interaction between age and executive control was not significant after Jennings et al. used a Z-score transformation of the RTs, it is debatable whether RTs should be transformed when assessing additivity and interaction.

In addition, Fernandez-Duque and Black (2006) administered a modified version of the ANT to 13 undergraduate students, 13 older adults, and 13 Alzheimer's disease (AD) patients²⁷. The key difference from the original ANT was the use of invalidly cued target trials which constituted 25 % of the trials following a spatial cue. This allowed the authors to define the orienting component as the difference in performance between valid and invalid trials. With regard to differences related to aging, they found that 1) the executive network was affected by the alerting network both with the students and the older adults (i.e., the congruency effects were larger in the presence of the alerting cue; see also Callejas et al., 2005; Ishigami & Klein, 2009a/Chapter 2, 2010/Chapter 3), 2) the executive network was affected by the orienting network only with the older adults (i.e., the congruency effects were larger in the presence of the valid cue; see Callejas et al., 2005 and Ishigami & Klein, 2009a/Chapter 2, 2010/Chapter 3 for the same interaction in the opposite direction), 3) the alerting network score was greater for the older adults than for the students, 4) the orienting network did not differ between the two groups, and 5) the executive network of the older adults was as efficient as that of the students.

The results from these studies using the ANT do not support observations in the literature that aging has relatively little effect on phasic alertness (e.g., Nebes & Brady, 1993; Rabbitt, 1984). In contrast, studies using the ANT support observation that the aging has little effect on endogenous orienting (Brodeur & Enns, 1997; Hartley et al., 1990, E3; Lincourt et al., 1997; Tales et al., 2002b) and on executive control (D'Aloisio

²⁷ When data from the healthy older adults and the AD patients were compared, only the executive network showed a different patterns for the two groups; the congruency effects were greater for the AD patients than for the healthy older adults. This suggests a greater difficulty for the AD patients to ignore irrelevant information.

& Klein, 1990; Kramer et al., 1994; Madden & Gottlob, 1997; Wright & Elias, 1979, but see Waszak et al., 2010).

These studies show an importance and usefulness of the ANT for studying and comparing the attention networks with wide range of populations. One class of situation for which the ANTs might be useful is when repeated testing is required. Researchers, for example, may be interested in developing training programs to overcome age-related impairments in attention. To assess the efficiency of such a program, repeated testing would be required. Researchers have also been interested in evaluating the effects of attention training or rehabilitation on the specific components of attention in clinical populations (e.g., Pero, Incoccia, Caracciolo, Zoccolotti, & Formisano, 2006; Robertson, Tegner, Tham, Lo, & Nimmosmith, 1995; Serino et al., 2007, Sohlberg, McLaughlin, Pavese, Heidrich, & Posner, 2000; Sturm, Thimm, Kuest, Karbe, & Fink, 2006; Sturm, Willmes, Orgass, & Hartje, 1997; Thimm, Fink, Kust, Karbe & Sturm, 2006) and in healthy older populations (e.g., Bherer, Kramer, & Peterson, 2008). Thus, it is important to understand how performance of each network score changes when the ANT is repeatedly administered over time.

Despite the use of the ANT in pre-/post- testing (Jha, Krompinger, & Baime, 2007; Tang et al., 2007) and its potential use in clinical and aging studies (e.g., Robertson et al., 1995), little is known about how performance of the three attention networks changes over time with repeated administrations and whether performance in the two versions the ANT (i.e., the ANT and the ANT-I) changes in the same way. The only exception comes from a recent study of the performance of young adults on these tests by

Ishigami and Klein (2010/Chapter 3). They tested 10 young adults with the ANT and the ANT-I over 10 different sessions. They reported that scores of the attention components measured by both ANTs remained robust even after 10 sessions although executive control scores with both ANTs, and orienting scores with the ANT-I decreased with practice. The participants learned how to ignore irrelevant information and how to disengage from attended locations over time. The scores measured with the ANT-I were generally more reliable than with the ANT. In their study, both the ANT and the ANT-I were suggested to be a potential tool to measure the attention networks when tested repeatedly.

Replicating the method used by Ishigami and Klein (2010/Chapter 3), the primary objective of the current study is to examine the stability, robustness and reliability of the attention networks derived from both versions of the ANT over repeated testing in older adults. In addition, isolability of the network scores derived from each version will be examined. Then, two versions of the ANT will be compared to determine if there were any substantial differences in their utility and whether they were tapping the same three components of attention. As in Ishigami and Klein (2010/Chapter 3): the temporal stability of the scores will be examined by Analysis of Variances (ANOVAs) with session as a factor to determine whether the magnitude of the score was changing with practice on the task; the robustness of the scores will be examined using one-sample *t*-tests to evaluate the significance of each component's score in the different testing sessions; reliability (or intra-participant stability) will be examined by computing for each network the correlation across different combinations of sessions (as will be described in more

detail later); and, isolability will be examined by determining whether there are significant interactions among the measures of the networks in the ANOVAs and whether there are significant correlations among the three networks. A secondary objective is to examine effects of aging in the network scores. To our knowledge, no study has compared the network scores derived from the ANT and the ANT-I in older adults with those of young adults. Because they were tested under essentially identical conditions we will compare the results of older adults in the current study with those of the young adults in Ishigami and Klein (2010/Chapter 3).

Method

Participants

Ten participants (four females and six males) took part in the current experiment. They were recruited from the local community paid for their participation (\$10.00/session). The participants ranged in age from 65 to 76 (mean = 69.1 and SD = 3.6). All participants self-reported to be physically and mentally healthy (i.e., not having received a diagnosis of any mental disorders by a health practitioner) and to have normal or corrected-to-normal vision. All participants completed an informed consent form and the study was approved by the Dalhousie Sciences and Humanities Human Research Ethics Board.

Apparatus

We used a program written in Python (Michael A. Lawrence). A 17-inch MacBook Pro controlled stimulus presentation and response collection. The ANT is

based on a program developed by researchers at the Sackler Institute for Developmental Psychology. The ANT-I is based on a program developed by Callejas et al. (2005).

Stimuli and Design

The sequence of events for both tests can be seen in Figures 4.1.1 and 4.1.2. For more specific details we refer the reader to the original papers by Fan et al. (2002), Callejas et al. (2005), or to Ishigami and Klein (2009a/Chapter 2). The experiment contained four blocks for the ANT and seven blocks for the ANT-I. A practice block (24 trials) was followed by experimental blocks (three 96 trials/block for the ANT and six 48 trials/block for the ANT-I). Cue and target congruency conditions for the ANT and auditory signal, cue condition, and target congruency conditions for the ANT-I were orthogonally crossed in the experimental blocks. The 12 possible combinations from each condition were pseudo-randomly presented so that there were eight trials and four trials for each combination in a block for the ANT and the ANT-I, respectively.

Procedure

The instructions (both oral and written) emphasized the importance of quick and accurate responding. The participants were told to maintain fixation at the fixation cross all the time. They were encouraged to attend when and where indicated by the cues in the ANT. The experimenter was present only at the beginning of each session in the testing room to start the experiment and to answer participants' questions regarding the instructions. In both the ANT and the ANT-I, feedback following errors was given visually only in the practice blocks. Participants performed both versions of the ANT in each session, which lasted about an hour and this was repeated 10 times (i.e., 10 days).

The ANT and the ANT-I were administered in an alternating order across sessions. In addition, the order of the ANTs was counterbalanced across the participants. Intervals between consecutive sessions were not fixed and the mean interval was 6.7 days (SD = 5.1).

Results

Performance by Older Participants

ANT

For each participant, trials with improper responses (e.g., responses made before the target was presented) or trials with no responses were excluded (2.0%). Then, mean correct RT after eliminating extreme values (less than 200 ms and more than 1700 ms: less than 0.1% of the total analyzable data) and mean error rate were computed and subjected to analyses. Table 4.2.1 shows mean correct RT and error rate collapsed across session, and Figures 4.2.1.1 and 4.2.1.2 show mean correct RT and error rate for cue condition and target congruency as a function of session.

Stability and Isolability of the Network Scores

To permit comparison with the literature (which typically only has one session) analyses were done separately for Session 1 and Sessions 1-10. ANOVAs were used to examine stability (Do effects change over the 10 sessions?) and isolability (Do conditions interact?), and isolability was also analyzed using correlations.

ANOVAs

The mean correct RT and the mean error rate were submitted to ANOVAs with cue condition (center, spatial, double, and no cues), and target congruency (neutral,

congruent, and incongruent) as repeated-measures factors; Session (1-10) was also a factor for the Sessions 1-10 analyses.

Session 1 (Figure 4.3.1.1). For RT, the main effects of cue condition, $F(3, 27) = 63.08, p < .0001$, and target congruency, $F(2, 18) = 171.43, p < .0001$, were significant. The interaction between cue condition and target congruency was marginally significant, $F(6, 54) = 2.12, p = .066$. Here it can be seen that the congruency effect was greater when participants were alerted by non-spatial cues (double cue). For error rate, the main effect of target congruency was significant, $F(2, 18) = 3.66, p < .05$. No other effects or interactions were significant.

Sessions 1 - 10 (Figure 4.3.1.2). For RT, the main effect of session was significant, $F(9, 81) = 12.54, p < .0001$, reflecting decreasing RT over time (see Figure 4.6). The main effects of cue condition, $F(3, 27) = 94.00, p < .0001$, and target congruency, $F(2, 18) = 108.021, p < .0001$, were significant. The interaction between cue condition and target congruency was significant, $F(6, 54) = 4.85, p < .001$, reflecting some lack of independence among the networks. In addition, the interactions between session and cue condition and session and target congruency were significant, $F(27, 243) = 1.59, p < .05$ and $F(18, 162) = 6.69, p < .0001$, respectively. These patterns reflect practice effects that were due mainly to greater improvements over sessions in the double cue condition (Figure 4.2.1.1) and the incongruent condition (Figure 4.2.1.2). The three-way interaction between cue condition, target congruency, and session was not significant, $F(45, 486) = 0.87$. The practice effects for the alerting (no cue minus double cue) and the executive (incongruent minus congruent) networks were examined by running separate ANOVAs.

The mean alerting network scores and the mean executive network scores in RT were submitted to ANOVAs with session as a repeated-measures factor to examine quantitative patterns of performance in each network across the sessions. The main effect of session was significant, $F(9, 81) = 2.62, p < .05$, $F(9, 81) = 5.64, p < .0001$, for the alerting and the executive networks, respectively; the alerting scores increased and the executive scores decreased as the sessions progressed.

For error rate, the main effect of congruency, $F(2, 18) = 8.04, p < .01$ was significant. The interaction between session and cue condition was marginally significant, $F(27, 243) = 1.49, p = .062$. No other effects were significant.

Correlational analyses

Session 1. Table 4.3.1 shows the correlations among the alerting, orienting, and executive networks. There were no significant correlations in the analysis of either the RT or error network scores, $ps > .05$. The lack of significant relationships was not surprising due to the small number of trials included in the analysis of just one session combined with the small number of participants.

Sessions 1-10. Means from the 10 sessions were entered in the correlation analyses. There were no significant correlations in the analysis of the RT network scores, $ps > .05$ (Table 4.3.1). In the analysis of the error rate the positive correlation between the alerting and the orienting network scores and the negative correlation between the orienting and the executive network scores were significant; participants with greater orienting effects showed greater alerting effects and smaller congruency effects. Gaining more power

when all the sessions were combined, the correlation analyses in error rate²⁸ suggest that the three networks may operate interactively. However, these results should be interpreted with caution due to the small number of participants in the analyses, the large number of relationships examined, and the confinement of the significant relationship to error rate.

Robustness of the Network Scores

Figure 4.4.1 summarizes scores of each attentional network for RT and error rate as a function of session. To examine robustness of the network scores, one sample *t*-tests were conducted one each score for each session. Despite the practice effects described above for the alerting and the executive networks, the tests on the RT data revealed that all the network scores were significantly different from zero in all 10 sessions, $ps < .01$. These results (see Figure 4.4.1) confirm that RTs from the ANT provide a robust index of each network in RT. For error rate, none of the alerting network scores was significantly different from zero across the sessions. The orienting network score was different from zero only in Session 9 ($p < .05$). The executive network score was significantly different from zero in Sessions 1, 2, 3, 4, 5 and 10 ($ps < .05$).

Reliability of the Network Scores

First, reliability was examined by correlating the first two sessions to allow comparison with the original ANT study's correlational analyses between Sessions 1 and 2 (Fan et al., 2002). Then, reliability including different numbers of consecutive sessions

²⁸ Even though errors are not normally distributed, we report the results with untransformed data because the literature on inter-network correlations has more often than not analyzed them untransformed. However, we did transform the errors (arcsine-transformation) and repeat the correlation analyses with the ANT and the ANT-I. Patterns are similar except for two correlations; correlation between the alerting and the orienting networks, $r(8) = .41$, and correlation between the orienting and the executive networks, $r(8) = -.01$, when all sessions were included, were not significant with the transformed data with the ANT.

was examined using a modified split-half correlation. In this permutation method²⁹, trials to be analyzed were randomly split into two halves 10,000 times, a correlation was computed for each split, and reliability was the mean of the 10,000 correlations.

With RT, the correlation between Sessions 1 and 2 was significant for the alerting and the orienting networks (Table 4.4), and marginally significant for the executive network ($p = .08$, by a non-directional t -test). These results are very similar to Fan et al. (2002) who, reported that the correlations between Sessions 1 and 2 were significant for all three network scores. None of the correlations between Sessions 1 and 2 for error rate were significant in the current study.

Results of the modified split-half reliability analyses as a function of number of consecutive sessions included in the analysis can be seen in Figure 4.5.1³⁰. The alerting network was significantly reliable (i.e., correlated) for RT when more than the first six sessions were included, but not for error rate regardless of the number of the sessions included. The orienting network was significantly reliable when more than the first three and four sessions were included for RT and error rate, respectively. The executive network was significantly reliable when more than the first two and six sessions were included for RT and error rate, respectively. It can be seen from Figure 4.5.1 that reliability is better in general when more data were included.

²⁹ We thank Michael A. Lawrence for proving us with R scripts for the modified split-half correlational analyses.

³⁰ The same analysis was conducted for each network for each session in a separate analysis. Reliability fluctuated across session. The alerting and the orienting network scores were not reliable for any of the sessions both in RT and error rate. The executive network scores were reliable only for Sessions 2, 3, 8, 9 and 10 in RT.

ANT-I

For each participant, trials with improper responses (e.g., responses made before the target was presented) or trials with no responses were excluded (1.8%). Then, mean correct RT after eliminating extreme values (less than 200 ms and more than 1700 ms: less than 0.1% of the total analyzable data) and mean error rate were computed and subjected to analyses. Table 4.2.2 shows mean correct RT and error rate collapsed across session, and Figures 4.2.2.1-3 show mean correct RT and error rate for target congruency, auditory signal, and cue condition as a function of session for the ANT-I.

Stability and Isolability of the Network Scores

The mean correct RT and the mean error rate were submitted to ANOVAs with auditory signal (tone and no tone), cue condition (valid, invalid, and no cue), target congruency (congruent and incongruent) as repeated-measures factors and Session (1-10) for the Sessions 1-10 analyses.

Session 1 (Figure 4.3.2.1). For RT, the main effects of auditory signal, $F(1, 9) = 12.95, p < .01$, cue condition, $F(2, 18) = 22.10, p < .0001$, and target congruency, $F(1, 9) = 55.65, p < .0001$, were significant. Here it can be seen that participants were faster to respond in the presence of auditory signals, valid cues, and congruent distractors. Interactions were analyzed excluding data from the no cue trials (cue condition) because the orienting network is measured by subtracting performance in the valid cued condition from that in the invalid cue condition (Callejas et al., 2005). The interaction between auditory signal and cue condition was marginally significant, $F(1, 9) = 4.38, p = .066$, reflecting that the cueing effect was greater in the tone (97 ms) than no tone (64 ms) conditions. No other

effects were significant. The pattern of interactions did not replicate what has been reported with young adults by Callejas et al. (2005) and Ishigami and Klein (2009a/Chapter 2, 2010/Chapter 3) both of whom found that the executive score was larger when participants had been alerted (see also Fernandez-Duque & Black, 2006; Posner, 1994) and when the targets were invalidly cued (see also Funes, Lupianez, & Milliken, 2007; but see Fernandez-Duque & Black, 2006).

For error rate, the interaction between cue condition and target congruency was marginally significant, $F(1, 9) = 3.83, p = .082$ and the three-way interaction between auditory signal, cue condition, and congruency was marginally significant, $F(1, 9) = 3.70, p = .087$, reflecting that the congruency effect with the invalid condition was different for the tone and the no tone conditions. No other effects were significant.

Sessions 1-10 (Figure 4.3.2.2). Session (1-10) was included in the analyses as a repeated-measures factor. For RT, the main effect of session was significant, $F(9, 81) = 10.43, p < .0001$, reflecting decreasing RT over time (see Figure 4.6). The main effects of auditory signal, $F(1, 9) = 47.11, p < .0001$, cue condition, $F(2, 18) = 150.83, p < .0001$, and target congruency, $F(1, 9) = 79.98, p < .0001$, were significant. Here it can be seen that participants were faster to respond in the presence of auditory signals, valid cues, and congruent distractors. The interaction between cue condition and target congruency was significant, $F(1, 9) = 6.75, p < .05$, reflecting that the congruency effect was greater for the invalid (86 ms) than for the valid (74 ms) conditions. This is different from the results with older adults in Fernandez-Duque and Black (2006) who reported the opposite interaction between the executive network and the orienting network (congruency effects were 125 ms and 67 ms for the valid and invalid condition, respectively). Note, however,

that their peripheral cue was informative (75% valid) while ANT-I's peripheral cue was uninformative, suggesting another possible difference between endogenous and exogenous orienting (see Klein, 2009). The interaction between auditory signal and cue condition was significant, $F(1,9) = 24.03, p < .001$, reflecting the greater cueing effect in the tone (91 ms) than the no tone (74 ms) conditions. The interaction between target congruency and session, $F(9, 81) = 5.18, p < .0001$, was significant. Consistent with the ANT, it can be seen from Figure 4.2.2.3 that the practice effect in the executive network was due mainly to an improvement in the incongruent condition. The interaction between auditory signal and target congruency was not significant, $F(1,9) = 0.05$. The lack of the interaction between alerting signal and target congruency is inconsistent with the results with older adults in Fernandez-Duque and Black (2006) who reported a presence of such interaction. Note, however, that their alerting signal was visual and the ANT-I's was auditory. Thus, the difference may not be a direct inconsistency. No other effects were significant. The practice effects for the executive network were examined by running a separate ANOVA. The mean executive network scores in RT were submitted to an ANOVA with session as a repeated-measures factor to examine quantitative patterns of performance across the sessions. The main effect of session was significant, $F(9, 81) = 5.01, p < .0001$; the executive effects decreased as the sessions progressed.

For error rate, the main effect of session was significant, $F(9, 81) = 2.12, p = .037$. The main effect of target congruency, $F(1, 9) = 12.56, p < .01$, was significant. Here it can be seen that participants were more accurate in the presence of congruent distractors. The three-way interaction between cue condition, target congruency, and session was significant, $F(9, 81) = 2.06, p < .05$, reflecting that the congruency effect

with the invalid condition was different for different sessions. The four-way interaction between session, auditory signal, cue condition, and target congruency was marginally significant, $F(9, 81) = 1.80, p = .081$. No other interactions were significant.

*Correlational analyses*³¹

Sessions 1: There were no significant correlations in the network scores in RT and error rate (Table 4.3.2).

Sessions 1-10: There were no significant correlations in the RT and error network scores (Table 4.3.2).

Robustness of the Network Scores

Figure 4.4.2 summarizes scores of each attentional network for RT and error rate as a function of session. Despite the practice effects described above for the executive network, one sample *t*-tests on the RT data revealed that all the network scores were significantly different from zero across all ten sessions, $ps < .05$. For error rate, none of the alerting effects were significantly different from zero across the 10 sessions. The orienting and executive effects were significantly different from zero only in Sessions 3 and 8, and Sessions 3, 4, and 8 ($ps < .05$), respectively.

Reliability of the Network Scores

The correlation between Sessions 1 and 2 was significant only for the executive network with RT and error rate (Table 4.4). The correlation was not significant for the alerting and the orienting networks.

³¹ The alerting network scores in the correlation analyses were calculated including all trials. As with the ANOVA analyses above, to provide a purer measure of alerting, analyses were also carried out excluding the valid and invalid cue conditions. Significance of the correlations involving the networks was the same as those including all trials.

Results of the modified split-half reliability analyses as a function of number of consecutive sessions included in the analysis can be seen in Figure 4.5.2³². For the alerting network in RT, the reliabilities seem to increase with increasing number of sessions. However, reliabilities were significant only when more than nine sessions were included. For error rate, regardless of the number of sessions included the alertness reliability did not achieve significance. For the orienting network in RT, reliabilities were stable from the first session and were significant regardless of the number of sessions included. For error rate, the reliabilities seem to increase with increasing numbers of sessions, but regardless of the number of sessions included, they were not significant. For the executive network in RT, reliabilities were stable from the first session and were significant regardless of the number of sessions included. For error rate, reliabilities were significant so long as more than two sessions were included.

Comparing the Network Scores Generated by the Two Tests

In this section we will compare the magnitudes of the network scores measured by the two tests and we will explore the correlation between corresponding scores (Table 4.5). At the start, we should remind the reader that alerting and orienting are measured somewhat differently (see Introduction) by the ANT and the ANT-I, while the two tests assess executive control in the same manner. For RT, the alerting network scores generated by the ANT and ANT-I were significantly different when all trials were included with the ANT-I, but not different when only the no cue trials (cue condition)

³² The same analysis was conducted for each network for each session in a separate analysis. Reliability fluctuated across the sessions. The alerting network scores were reliable only for Sessions 10 in RT. The orienting network scores were reliable for Sessions 1, 2, 3, 4, and 8 with RT and for Session 7 in error rate. In RT, the executive network scores were reliable for all the sessions except 5 and 10.

were included with the ANT-I. The correlation between these scores, while moderate ($r = .38$), was not significant. The difference between the orienting network scores measured with the two tests was not significant. The correlation between these scores was not significant and very close to zero. The executive network scores from the two tests were significantly different with the ANT generating larger scores than the ANT-I. The correlation between these scores ($r = .96$) was significant. For error rate, the alerting, orienting, and executive network scores measured with the two tests were not significantly different. The correlations between the two tests were not significant for the alerting and the orienting network scores while the correlation was significant for the executive network scores.

Effects of Aging on the Components of Attention

Comparing the attention networks between the older and the young adults (Ishigami & Klein, 2010/Chapter 3) was the secondary objective. Before analyzing the networks, comparisons of overall RT and error rate as a function session between the two groups are reported (Figure 4.6). The mean correct RT and the mean error rate from the ANT and the ANT-I were separately submitted to ANOVAs with session as a repeated-measures factor and group as a between-participant factor. For the ANT in RT, the main effect of group was significant, $F(1, 18) = 13.258, p < .001$. The main effect of session, $F(9, 162) = 9.357, p < .00001$, and its interaction with group, $F(9, 162) = 3.968, p < .0001$, were significant. For error rate, the main effect of group, $F(1, 18) = 15.424, p < .0001$, and its interaction with session, $F(1, 162) = 2.398, p < .05$, were significant. The main effect of session was not significant, $F(9, 162) = .716$. These patterns show that the

older adults were slower to respond (692 vs. 559 ms) but more accurate (.007 vs. .029, proportion errors) than the young adults in overall performance. In addition, the older adults became faster and more accurate as the sessions progressed. Similarly, for the ANT-I, the main effects of group was significant for RT, $F(1, 18) = 33.231, p < .00001$. The main effect of session, $F(9, 162) = 7.306, p < .00001$, and its interaction with group, $F(9, 162) = 1.955, p < .05$, were significant. For error rate, the main effect group was significant, $F(1, 18) = 25.700, p < .00001$. The main effect of session, $F(9, 162) = 2.265, p < .05$, and its interaction with group, $F(9, 162) = 2.633, p < .001$, were significant. Similar to the ANT, these patterns show that the older adults were slower to respond (717 vs. 501 ms) but more accurate (.005 vs. .032, proportion errors). In addition, the older adults became faster and more accurate as the sessions progressed.

Network scores for both the older and younger participants were computed using the same procedures (as described above and in Ishigami and Klein (2010/Chapter 3). To permit comparison with the above analyses, analyses were done separately for Session 1 and Sessions 1-10 (Figure 4.7). The network scores in RT and error rate were submitted to ANOVAs with group (young and older adults) as a between-participant factor and session as a repeated-measure factor (for the Sessions 1-10 analyses).

ANT

Session 1. For RT network scores, the main effects of group were not significant for the alerting and the executive networks, $F(1, 18) = .058$ and $.310$, respectively. The main effect of group was significant for the orienting network, $F(1, 18) = 23.806, p < .0001$, showing that the scores were greater for the older adults (80 ms) than for the young adults

(21 ms). For error rate network scores, the main effects of group were not significant for the alerting and the orienting networks, $F(1, 18) = .167$ and 1.338 , respectively. The main effect of group was significant for the executive network, $F(1, 18) = 11.070$, $p < .01$, showing that the scores were greater for the young adults (.046) than for the older adults (.012).

Sessions 1-10. For the alerting network in RT, the main effect of group was not significant, $F(1, 18) = .035$. The main effect of session was significant, $F(9, 162) = 1.937$, $p < .05$, and its interaction with group was marginally significant, $F(9, 162) = 2.520$, $p = .050$. The cause of the interaction was partly due to the practice effects observed with the older adults (see page 121). With the orienting network in RT, the main effect of group was significant, $F(1, 18) = 36.114$, $p < .00001$, showing that the scores were greater for the older adults (72 ms) than for the young adults (24 ms). The main effect of session and its interaction with group were not significant, $F(9, 162) = 1.438$ and 1.013 , respectively. With the executive network in RT, the main effect group was not significant, $F(1, 18) = 1.954$. The main effect of session was significant, $F(9, 162) = 13.835$, $p < .00001$, reflecting the practice effects. The interaction between group and session was not significant, $F(9, 162) = 1.005$.

For the alerting network in error rate, the main effect of group was significant, $F(1, 18) = 9.936$ $p < .01$, showing that the alerting network scores were greater for the young adults (.007) than for the older adults (-.002). The main effect of session and its interaction with group were not significant, $F(9, 162) = 1.416$ and $.607$, respectively. For the orienting network in error rate, the main effect of group was significant, $F(1, 18) =$

11.188, $p < .01$, showing that the orienting network scores were greater for the young adults (.013) than for the older adults (-.004). The main effect of session and its interaction with age were not significant, $F(9, 162) = 1.154$, and .954, respectively. For the executive network, the main effect of group was significant, $F(1, 18) = 16.158$, $p < .00001$, showing that the executive network scores were greater for the young adults (.060) than for the older adults (.010). The main effect of session and its interaction with group were not significant, $F(9, 162) = 1.831$ and 1.265, respectively.

ANT-I

Session 1. For RT network scores, the main effects of group were marginally significant for the alerting, $F(1, 18) = 4.334$, $p = .052$, and for the orienting networks, $F(1, 18) = 3.901$, $p = .064$. The alerting scores were greater for the young adults (41 ms) than for the older adults (19 ms). The orienting scores were greater for the older adults (80 ms) than for the young adults (47 ms). The main effect of group was not significant for the executive network, $F(1, 18) = 1.471$. For error rate network scores, the main effects of group were significant for the alerting network, $F(1, 18) = 5.590$, $p < .05$, and for the executive network, $F(1, 18) = 12.563$, $p < .01$. The alerting network scores were greater for the older adults (.002) than for the young adults (-.011). The executive network scores were greater for the young adults (.039) than for the older adults (.005). The main effect of group was marginally significant for the orienting network, $F(1, 18) = 3.455$, $p = .079$, showing that the scores were greater for the young adults (.015) than for the older adults (.001).

Sessions 1-10. For alerting network in RT, the main effect of group was marginally significant, $F(1, 18) = 3.277, p = .087$, showing that the scores were greater for the young adults (44 ms) than for the older adults (24 ms). The main effects of session and its interaction with group were not significant, $F(9, 162) = .982$ and $.493$, respectively. For the orienting network in RT, the main effect of group was significant, $F(1, 18) = 56.332, p < .00001$, showing that the scores were greater for the older adults (83 ms) than for the younger adults (30 ms). The main effect of session was significant, $F(9, 162) = 2.060, p < .05$. The cause of this effect was partly due to the practice effects observed with the older adults above. However, the interaction between session and group was not significant, $F(9, 162) = .997$. For the executive network in RT, the main effect of group was not significant, $F(1, 18) = 2.813$ (63 ms and 80 ms for the young and the older adults, respectively). The main effect of session was significant, $F(9, 162) = 10.693, p < .00001$, showing the practice effects. The interaction between group and session was not significant, $F(9, 162) = .683$.

For the alerting network in error rate, the main effects of group and session were not significant, $F(1, 18) = .234$ and 1.319 , respectively. The interaction between group and session was significant, $F(9, 162) = 2.027, p < .05$, showing that the scores increased for the young adults but remained stable for the older adults. For the orienting network in error rate, the main effect of group was significant, $F(1, 18) = 22.225, p < .001$, showing that the orienting network scores were greater for the young adults (.016) than for the older adults (.003). The main effect of session and its interaction with age were not significant, $F(9, 162) = .849$, and $.966$, respectively. For the executive network in error

rate, the main effect of group was significant, $F(1, 18) = 23.718, p < .001$, showing that scores were greater for the young adults (.050) than for the older adults (.006). The main effect of session, $F(9, 162) = 3.349, p < .001$, and its interaction with group, $F(9, 162) = 2.065, p < .05$, were significant, showing that the main effect of session was due mainly to the unstable scores for the young adults.

Discussion

The present experiment was conducted to examine, in older adults, the stability, isolability, robustness, and reliability of the measures of attention networks (alerting, orienting, and executive) derived from two versions of the ANT over repeated testing and difference between the two versions of the ANTs. In addition, effects of aging on the network scores were examined.

Performance by Older Adults

We observed practice effects for the executive network scores with both the ANT and the ANT-I and practice effects for the alertness scores in the ANT (Figures 4.4.1 and 4.4.2). Despite these practice effects, both the ANT and the ANT-I produced a robust index of each attention network even after the 10 sessions of each test. Consistent with the literature, there was some lack of independence among the networks in both tests. Overall, the reliability of the network scores was found to be slightly greater with the ANT-I than the ANT.

The practice effects for the executive network in RT in the ANT and ANT-I are clearly apparent. A close examination of Figures 4.2.1.2 and 4.2.2.3 shows that the decreases in the executive scores across the sessions are due mainly to a greater decrease

in RT in the incongruent condition than in the congruent condition. Thus, as the participants practice the task (across sessions) they learn how to ignore the irrelevant flanking arrows (see also Ishigami & Klein, 2010/Chapter 3).

Practice effects for alerting were also observed in the ANT; the alertness network score increased as the sessions progressed. The alerting network in the ANT is defined by the double cue and no cue conditions. A close examination of Figure 4.2.1.1 shows that the decrease in RT for the double cue condition is steeper than for the no cue condition. The participants seemed to learn to pay attention to the cues and thus to respond more quickly in the presence of the warning signals.

Our data largely replicate previous studies of the attention networks (Callejas et al., 2004; Fan et al., 2002; Ishigami & Klein, 2009a/Chapter 2, 2010/Chapter 3; Jennings et al., 2007) in showing that the three attention networks do not operate independently in all situations. Consistently, the cueing effect was greater in the presence of auditory warning signals. The congruency effects were smaller in the presence of valid cues. The reliability of the network scores is generally greater with the ANT-I than with the ANT when only one session is included. However, this difference in the reliability attenuates as more sessions are included in the analyses.

The network scores generated by the two tests were found to be significantly related to each other only in the executive network. This significant relation was expected because the executive effects are measured by the two tests using essentially the same conflicting and congruent arrows. Although the network scores for the alerting network were not significantly correlated, the correlation was moderate ($r = .38$).

Correlations between effects are limited by their reliabilities, and the reliabilities of the alertness scores for the older adults were considerably lower than those of the younger adults (Ishigami & Klein, 2010/Chapter 3, Table 4/Table3.4). While the actual correlation ($r = .38$) is moderate and not significant, when corrected for attenuation (Spearman, 1904) the correlation is substantially larger (.51). The network scores for orienting were not significantly related and the relationship was insubstantial. The orienting component of attention is measured quite differently in the two tests; whereas the 100% valid peripheral cue used in the ANT allows both endogenous and exogenous control to be operating, with the uninformative peripheral cues of the ANT-I orienting depends on the degree to which the cue captures attention exogenously. Not surprisingly, there appears to be no relation, whatsoever, between the orienting scores from the two tests.

Effects of Aging on the Components of Attention

The most consistent differences between the older adults and the young adults regardless of the version of the ANT were that 1) the older adults were slower to respond but more accurate than the young adults, showing speed-accuracy tradeoffs, and showing greater improvements in RT and error rate with practice, 2) the older adults showed greater orienting scores in RT, and 3) showed smaller executive scores in error rate (Figures 4.6-7) . Comparing the performance between the older adults and the young adults, we found that aging had some effects on the attention networks.

Alerting: Both older and young adults seem to respond to the target faster in the presence of the warning signal especially when the warning signal was visual (ANT). This pattern is consistent with the study using visual warning signals (Tales et al., 2002a),

but inconsistent with the studies using the ANT (Fernandez-Duque & Black, 2006; Jennings et al., 2007), especially Jennings et al. (2007) who showed that alerting effects were smaller for the older adults than for young adults. It is puzzling when comparing the results from the current study with those of Jennings et al. (2007), both of which should have power to detect differences (see below discussion for a motivational difference for a possible reason why the older adults in the current study showed alerting effects similar to those of the young adults). Different from the ANT, the alerting effects were greater for the young than the for the older adults when the warning signal was auditory (ANT-I). The pattern is inconsistent with the studies using auditory warning signals (Nebes & Brady, 1993; Rabbitt, 1984) (see below for a motivational difference for a possible reason why the difference was observed only with the ANT-I and relatedly why the results were inconsistent among the studies.). Thus, it is difficult to determine whether aging has some effects on phasic alertness.

Orienting: One of the most consistent differences between the older adults and the young adults is seen in orienting. The older adults showed greater cueing effects than the young adults in the presence of the visual cues with spatial information (spatial cue in the ANT and valid cue in the ANT-I). Note that orienting in the ANT is ‘relatively endogenous’ (i.e., hybrid of endogenous and exogenous orienting) while orienting in the ANT-I is purely exogenous. None of the studies using the ANT reported the effects of aging on the hybrid form of orienting elicited by informative peripheral cues (Fernandez-Duque & Black, 2006; Jennings et al., 2007). However, a close examination of Fernandez-Duque and Black’s data show that the difference is in the same direction as

ours. There are only a few more studies examining effects of aging on ‘relatively endogenous’ orienting (Folk & Hoyer, 1992; Hartley et al., 1990). Results from these studies are mixed. There are more studies examining effects of aging on pure endogenous orienting (i.e., using central arrow cue) (e.g., Brodeur & Enns, 1997; Folk & Hoyer, 1992; Greenwood et al., 1993; Hartley et al., 1990; Lincourt et al., 1997; Niseen & Corkin, 1985; Tales et al., 2002b). Results from these studies are also mixed. However, a close examination of their data show that the difference regardless of their statistical significance are generally in the same direction as ours. There are also more studies examining effects of aging on pure exogenous orienting (e.g., Brodeur & Enns, 1997; Festa-Martino et al., 2004; Greenwood et al., 1993; Tales et al., 2002b; Waszak et al., 2010). These studies report that exogenous orienting effects of the older and young adults are similar. However, a close examination of their data show that the non-significant differences are generally in the same direction as ours. Our results as well as the results in literature point to a pattern that orienting effects whether endogenous or exogenous can be greater for the older adults than the young adults.

One possible explanation for the greater orienting effects with the older than with the young adults in the current study is that the older adults might have greater difficulty in disengaging from attended locations. In the ANT, with its 100% valid peripheral cues this may slow performance on the baseline (center cue) trials because of the difficulty disengaging attention from the fixation. In the ANT-I, with its uninformative peripheral cues, this may slow performance on invalid trials because of the difficulty disengaging attention from peripheral cues that capture attention. In either case, the disengage deficit

would result in a larger orienting score. Because the ANT has no invalid condition and the ANT-I has no neutral (only a "no cue") condition, neither test can provide satisfactory, separate measures of the costs and benefits of cuing from which we could directly assess this proposal. Such a neutral condition, however, was present in the study by Fernandez-Duque and Black (2006), and their data numerically shows greater costs (invalid minus neutral) in their older participants (37 ms vs. 54 ms for the young and older adults, respectively) and equal benefits (neutral minus valid) for the two age groups (27 ms and 26 ms for the young and older adults, respectively). This is precisely the pattern one would expect if the older participants experienced difficulty disengaging attention from its current focus. However, this interpretation needs caution because of the mixed results among the studies and a possible speed-accuracy tradeoff. It is also possible that the difference in the orienting effects reflect different strategies between the two groups. The older adults had greater cueing effects in RT than the young adults, but the young adults had greater cueing effects in error rate than the older adults. These patterns could be interpreted as follows; age has no effect on the orienting network, per se, but the older adults focused on accuracy while the young adults focused on speed.

Executive control: Consistently the executive network scores in RT are numerically greater for the older than for the young adults even though the differences were not statistically significant. Greater executive network scores for the older adults with raw data is consistent with Jennings et al. (2007). In addition, studies in the literature report greater congruency effects with older than with young adults (D'Aloisio & Klein, 1990; Waszak et al., 2010; Zeef et al., 1996 Kramer et al., 1994, but see Madden &

Gottlob, 1997; Wright & Elias, 1979). Spatial separation between the distractors in the ANTs is relatively smaller than the other studies in the literature. It is possible that the older adults had hard time ignoring irrelevant information because it is presented close to the targets. In fact, Zeef et al. (1996) and D'Aloisio and Klein (1990) found greater congruency effects for older adults, but only when the smallest distance between targets and distractors was tested. Importantly, the executive network scores in error rate was greater for the younger adults than for the older adults in the current study. The greater congruency effects in RT are compensated by smaller congruency effects in error rate for the older adults while the pattern is reversed for the young adults - a similar pattern observed in orienting above. It is possible that the difference might diminish as in D'Aloisio and Klein (1990) if error rate is taken into consideration.

Further, we found somewhat different practice effects for the two age groups. First of all, only the older adults responded faster and more accurately as the sessions progressed. In addition, the practice effects upon alerting that we found with the older adults and which were confined to the ANT, were not observed in younger adults. We can only speculate why the older participants became more alert in the ANT and not in the ANT-I with practice and why they, but not the younger adults showed this effect. The difference between the ANT and the ANT-I may be due to the different meanings involved in the alerting signals in the alerting network for the two tests (visual in the ANT and auditory in the ANT-I). In the ANT, one of the visual cues is 100% valid and the participants are instructed to pay attention to it. Consequently, it is possible that the participants learned to pay attention to all the visual cues due to their attention being

allocated to cues in general. On the other hand, in the ANT-I, the participants were not instructed to pay attention to the auditory signals and there was no requirement to do so based on the primary task being visual. One of reasons why the older adults in the current study and not the younger adults show the practice effects may be that older adults try harder to follow the instructions (e.g., pay attention to the spatial cues) than the younger adults. This may be a reason why the older adults in the current study, but not the older adults in Jennings et al. (2007), showed similar alerting effects to the young adults; there may have been difference in term of motivation to follow the instructions between the participants in the two studies. It may not be appropriate, however, to interpret the young adults' alerting effects in the same way. Similarly, the non-significant relationships especially in alerting and orienting between the ANT and the ANT-I with the older adults may be related to the degree to which the older participants pay attention differently to different warning cues (alerting) and visual cues (orienting).

Relatedly, it is possible that the older adults might be able to efficiently ignore the auditory signals, which did not share the same modality as the targets. This may be why the older adults showed smaller alerting effects than the younger participants with the ANT-I - different from the studies in the literature. There was a difference in interactions in the ANT-I between the younger and the older adults. The finding with young adults that when alert the effect of congruency (executive score) is greater (see also Ishigami & Klein, 2009a/Chapter 2) was not found with the older participants. Note that Fernandez-Duque and Black (2006) reported an interaction with their older participants between the

alerting and the orienting networks. Their alerting network was defined by visual cues. The older adults' ability to ignore irrelevant information may be modality specific.

Conclusion

With older adults, both ANTs are useful tools to measure attention components, namely alerting, orienting, and executive functions, within one session, which takes less than 30 minutes. The current study shows that scores of these attention components remain robust even after 10 sessions. This enables either attention network test to be used in applications that require repeated testing. It is important to note, however, that executive control scores with both ANTs decrease, and alerting with the ANT increases with practice. Therefore, an untreated control group would be warranted in some designs. While the network scores are robust against practice, their reliability is generally lower than is ideal for many purposes. Unlike young adults, older adults may more assiduously follow the instructions they are given. In addition, older adults may focus more on accuracy than on speed. Interpretation of age differences in attention network scores is complicated by these differences between the two age groups in motivation and strategy.

Table 4.1
Conditions and their levels in the ANT and the ANT-I.

	ANT	ANT-I
Auditory signal	NA	Tone
		No tone
Cue condition (ANT) Visual cue (ANT-I)	No cue	No cue
	Center cue	Valid
	Double cue	Invalid
	Spatial	
Target congruency	Neutral	Congruent
	Congruent	Incongruent
	Incongruent	

Subtractions for each network

	ANT	ANT-I
Alerting	No cue - Double cue	No tone - Tone
Orienting	Center cue - Spatial cue	Invalid - Valid
Executive	Incongruent - Congruent	Incongruent - Congruent

Table 4.2.1

Mean RT (ms) and error rate (proportion incorrect) (between parenthesis) for the ANT.

	No cue	Center	Double	Spatial
Congruent	726 (0.002)	699 (0.002)	668 (0.004)	626 (0.005)
Incongruent	808 (0.011)	793 (0.010)	774 (0.013)	719 (0.018)
Neutral	682 (0.007)	637 (0.005)	610 (0.008)	569 (0.007)

Table 4.2.2

Mean RT (ms) and error rate (proportion incorrect) (between parenthesis) for the ANT-I

	Tone			No tone		
	Valid	Invalid	No cue	Valid	Invalid	No cue
Congruent	615 (0.001)	701 (0.004)	682 (0.004)	638 (0.002)	706 (0.001)	729 (0.002)
Incongruent	689 (0.008)	785 (0.011)	764 (0.007)	711 (0.006)	793 (0.011)	805 (0.008)

Table 4.3.1

Correlations between attention networks in the ANT in Session 1.

RT	Alerting	Orienting	Error Rate	Alerting	Orienting
Orienting	-0.02		Orienting	0.60	
Executive	-0.03	-0.13	Executive	0.35	0.07

Correlations between attention networks in the ANT in Sessions 1-10.

RT	Alerting	Orienting	Error Rate	Alerting	Orienting
Orienting	0.46		Orienting	0.77*	
Executive	-0.03	-0.12	Executive	-0.16	-0.65*

Table 4.3.2

Correlations between attention networks in the ANT-I in Session 1.

RT	Alerting	Orienting	Error Rate	Alerting	Orienting
Orienting	0.10		Orienting	-0.10	
Executive	0.14	-0.11	Executive	0.45	-0.38

Correlations between attention networks in the ANT-I in Sessions 1-10.

RT	Alerting	Orienting	Error Rate	Alerting	Orienting
Orienting	-0.26		Orienting	-0.28	
Executive	-0.27	0.07	Executive	-0.24	-0.24

* $p < .05$

** $p < .001$

Table 4.4

Reliability of the three attention networks from correlational analyses between Sessions 1 and 2 (Fan et al, 2002, Ishigami & Klein, 2010/Chapter 3, and current study) and from a variation of split-half correlational analyses including all the sessions (Ishigami & Klein, 2010/Chapter 3 and current study). Fan et al. and Ishigami & Klein tested young adults.

	Network	Sessions 1-2 (Fan et al.)	Sessions 1-2 (Ishigami & Klein)	Sessions 1-2 (Current study)	Sessions 1-10 (Ishigami & Klein)	Sessions 1-10 (Current study)
ANT	Alerting	0.52**	-0.02	0.73*	0.80**	0.73*
	RT Orienting	0.61**	0.57	0.70*	0.65*	0.87**
	Executive	0.77**	0.86**	0.57	0.93**	0.92**
	Alerting	N/A	0.20	0.35	-0.02	-0.07
	Error Orienting	N/A	0.42	0.23	0.32	0.79**
	Executive	N/A	0.45	-0.07	0.93**	0.69*
ANT-I	Alerting	N/A	0.64*	-0.11	0.98**	0.76*
	RT Orienting	N/A	0.77**	0.17	0.81**	0.76*
	Executive	N/A	0.48	0.79**	0.89**	0.96**
	Alerting	N/A	0.28	-0.24	0.70*	0.29
	Error Orienting	N/A	0.43	-0.11	0.02	0.40
	Executive	N/A	0.63	0.73*	0.92**	0.69*

* $p < .05$

** $p < .01$

Table 4.5

Network scores generated by the ANT and the ANT-I, their difference, and the correlation between the scores from the two different versions of the ANT.

	Network	ANT	ANT-I	<i>t</i> (9)	<i>r</i> (9)
RT	Alerting	54.85	23.93 ^a	6.22*	0.38
	Orienting	71.75	82.86	-1.16	-0.10
	Executive	94.24	79.60	5.53*	0.96*
Error	Alerting	-0.00	-0.00 ^b	-0.75	0.38
	Orienting	-0.00	0.00	-1.77	0.10
	Executive	0.01	0.01	1.12	0.90*

* $p < .01$

^a The alerting network scores were calculated including all trials. When excluding the valid and invalid visual cue conditions, to provide a purer measure of alerting, the alerting score was 43.82 ms. The difference and the correlation between the scores were not significant.

^b The alerting network scores were calculated including all trials. When excluding the valid and invalid visual cue conditions, to provide a purer measure of alerting, the alerting score was 0.00 ms. The difference and the correlation between the scores were not significant.

Figure 4.1.1

Experimental procedure of the ANT (Fan et al., 2002). (I) the four cue conditions. (II) the six target stimuli used in the present experiment. and (III) an example of the procedure; a spatial cue is presented followed by a target (central) arrow.

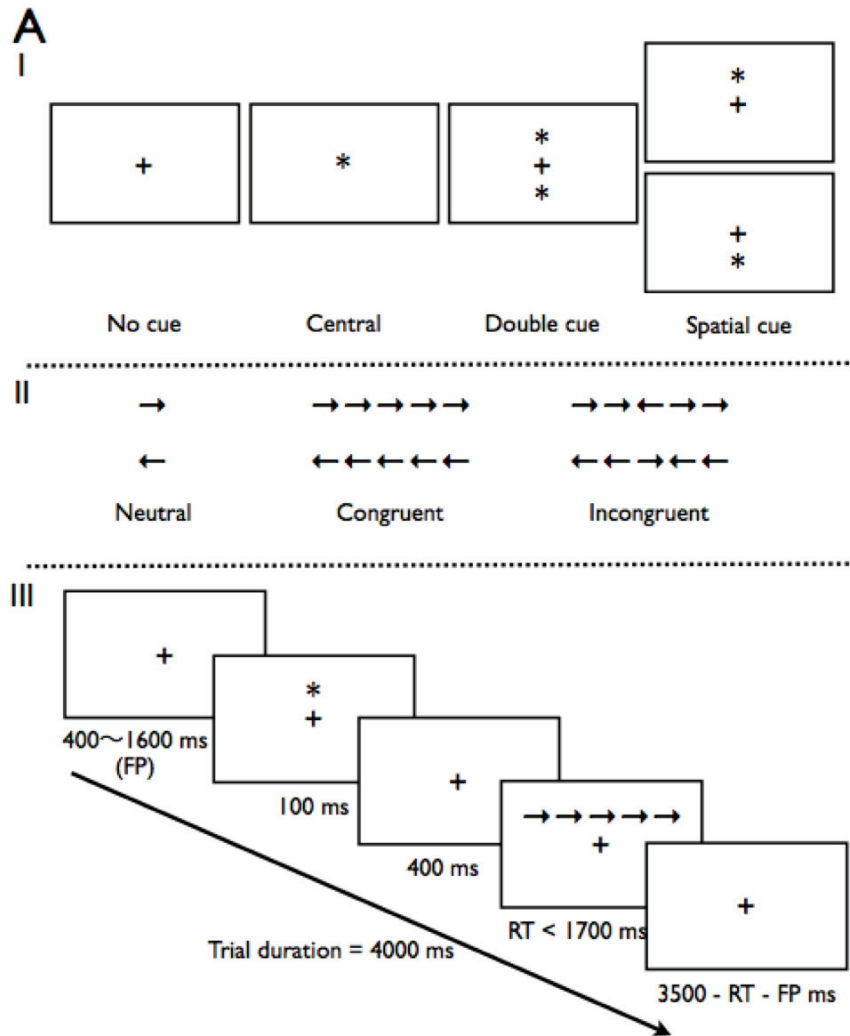


Figure 4.1.2

Experimental procedure of the ANT-I (Callejas et al., 2005). An example of the procedure; an auditory tone is presented, followed by a valid cue, and a target (central) arrow flanked by congruent arrows.

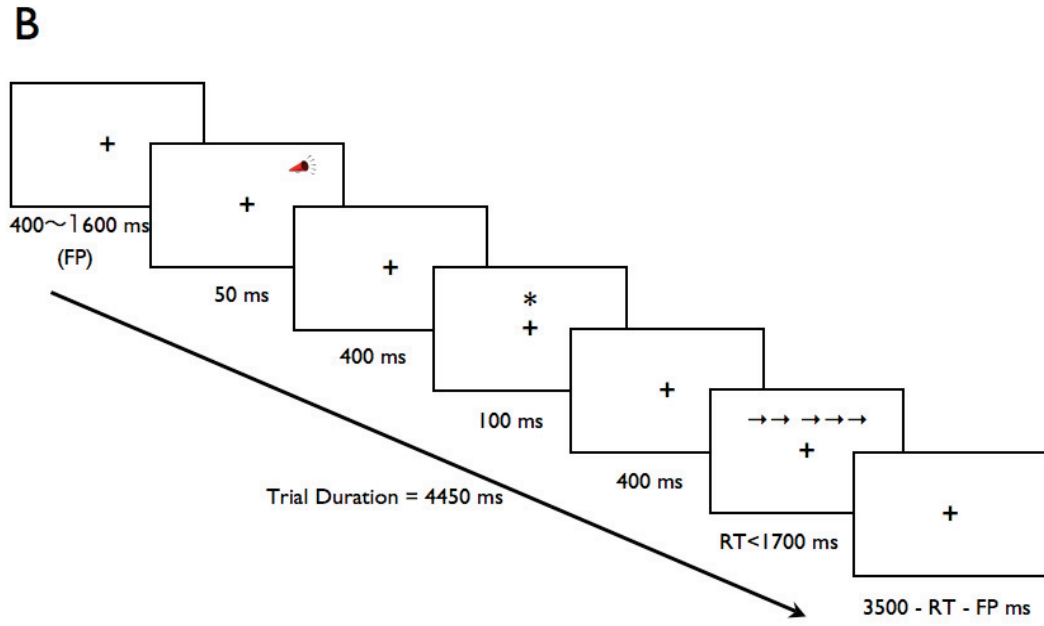


Figure 4.2.1.1

Mean correct RT and error rate on the ANT as a function of cue condition and session.

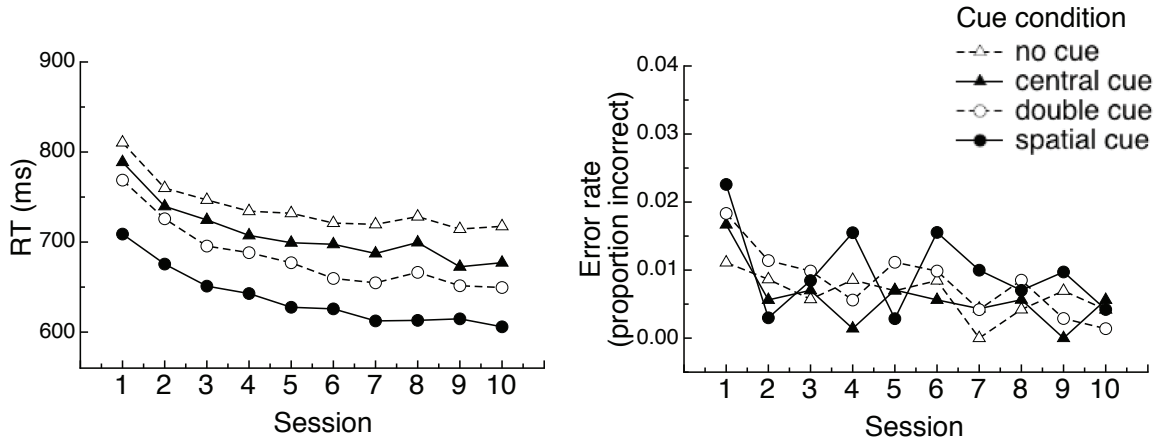


Figure 4.2.1.2

Mean correct RT and error rate on the ANT as a function of target congruency and session.

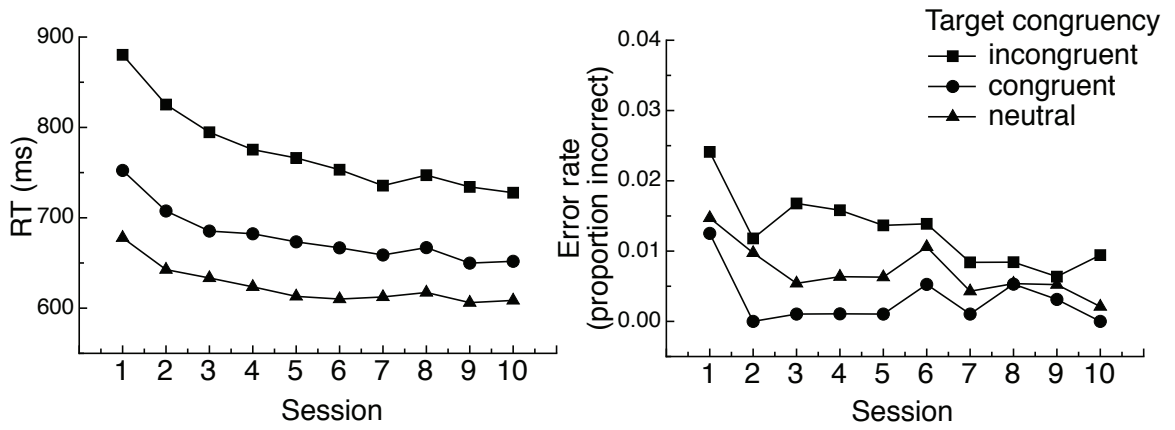


Figure 4.2.2.1

Mean correct RT and error rate on the ANT-I as a function of auditory signal and session.

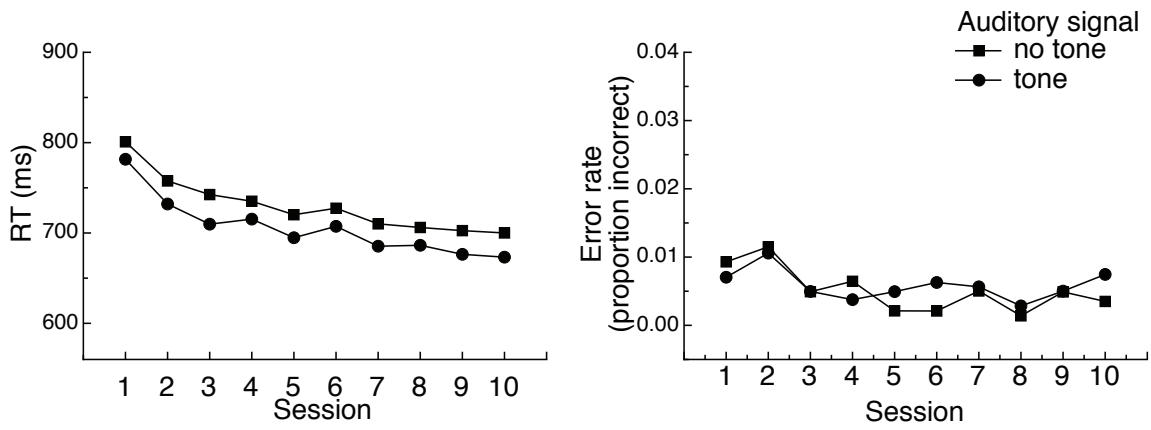


Figure 4.2.2.2

Mean correct RT and error rate on the ANT-I as a function of visual cue and session.

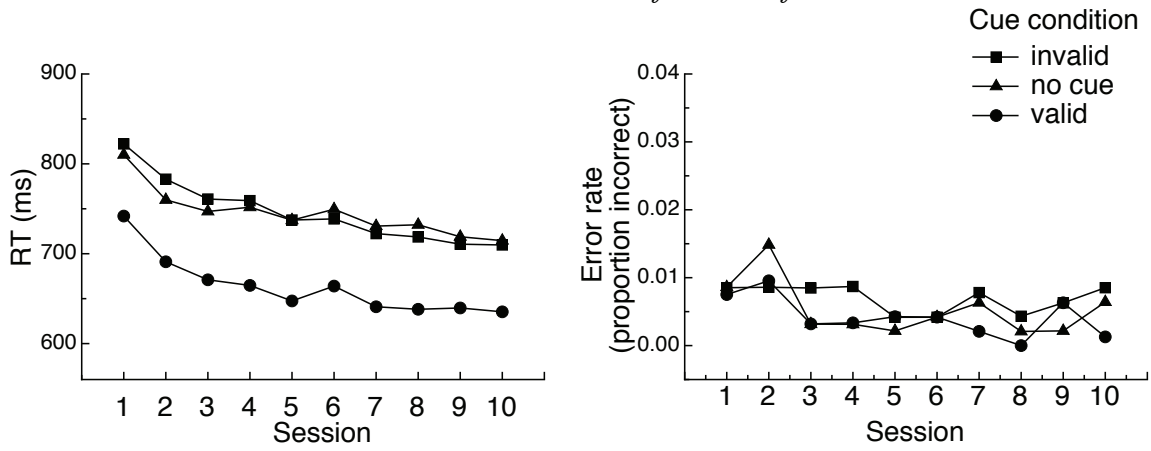


Figure 4.2.2.3

Mean correct RT and error rate on the ANT-I as a function of target congruency and session.

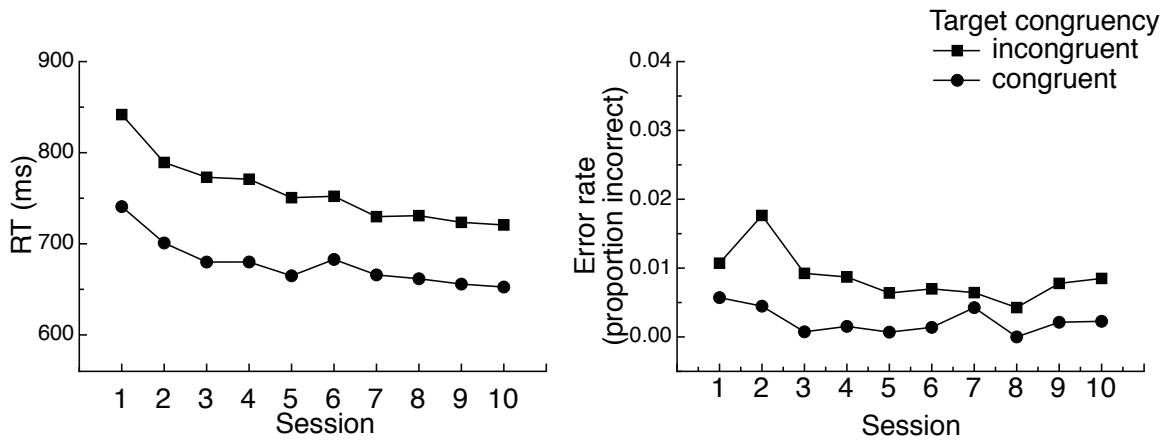


Figure 4.3.1.1

Mean correct RT and error rate on the ANT for Session 1 as a function of cue condition and target congruency.

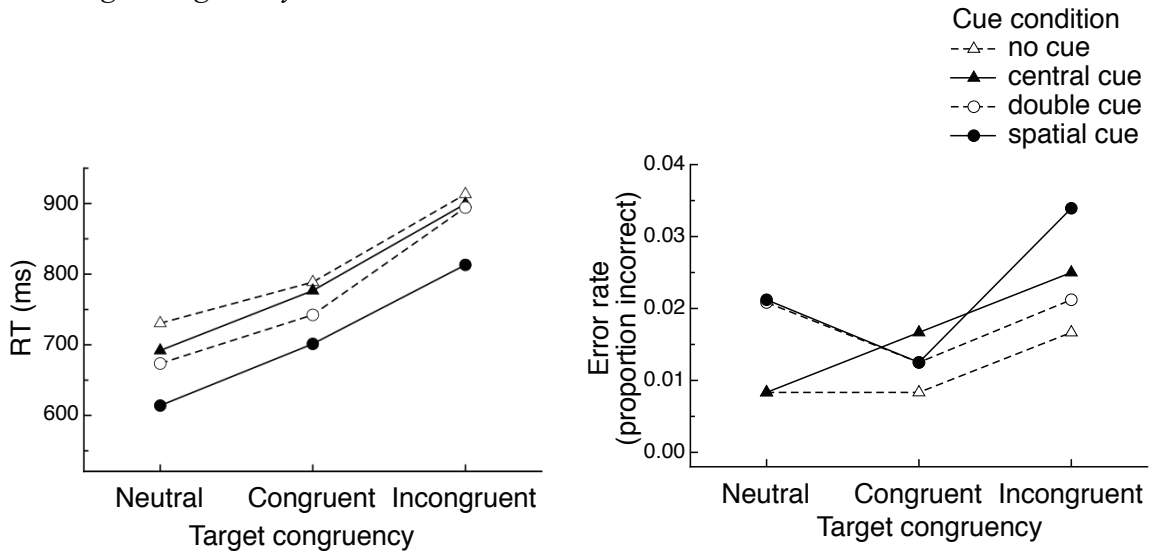


Figure 4.3.1.2

Mean correct RT and error rate on the ANT for Sessions 1-10 as a function of cue condition and target congruency.

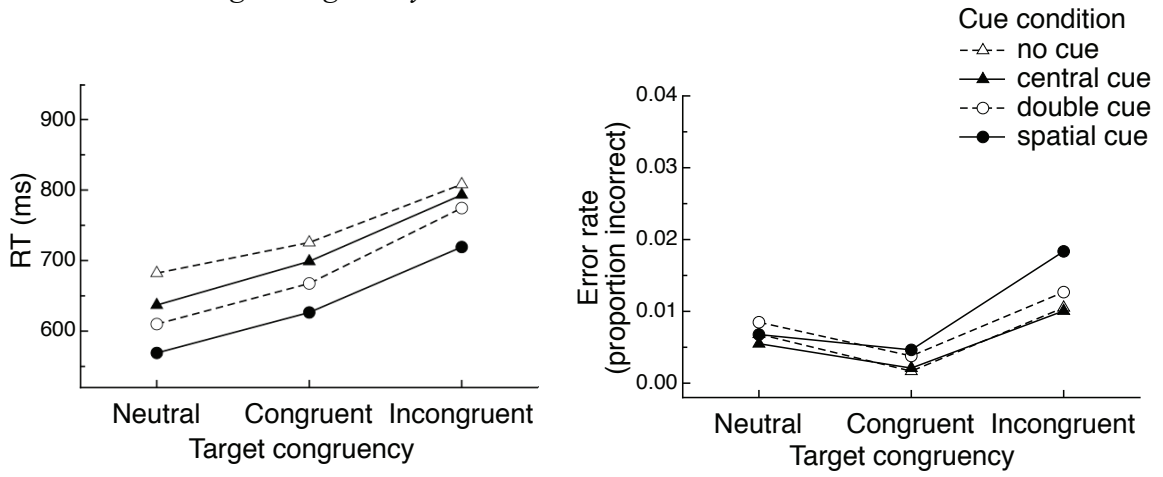


Figure 4.3.2.1

Mean correct RT and error rate for Session 1 on the ANT-I as a function of target congruency and auditory signal & validity.

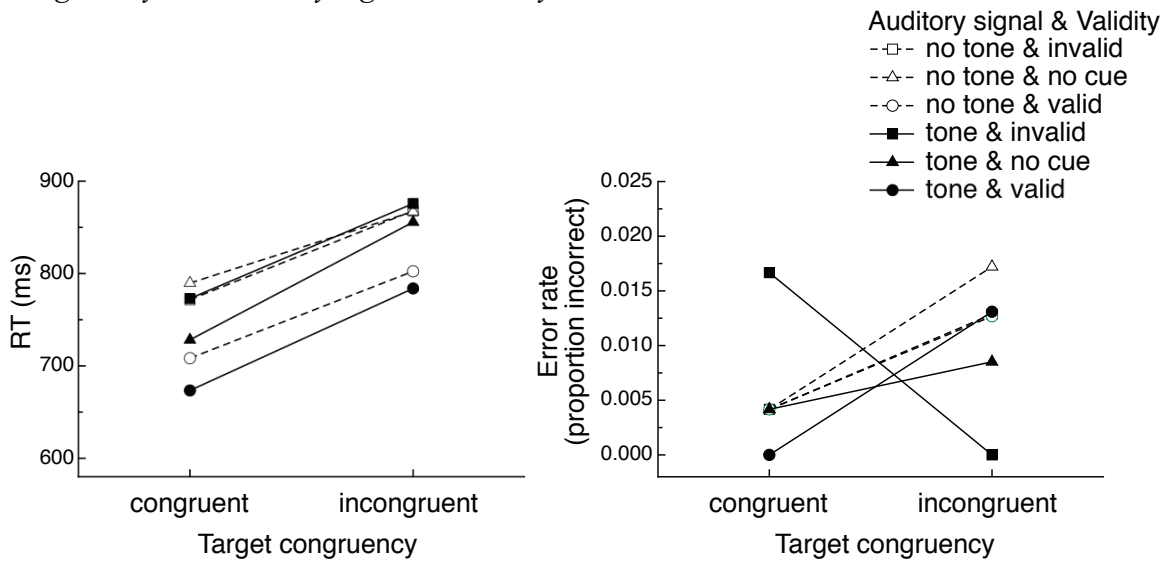


Figure 4.3.2.2

Mean correct RT and error rate for Sessions 1-10 on the ANT-I as a function of target congruency and tone & validity.

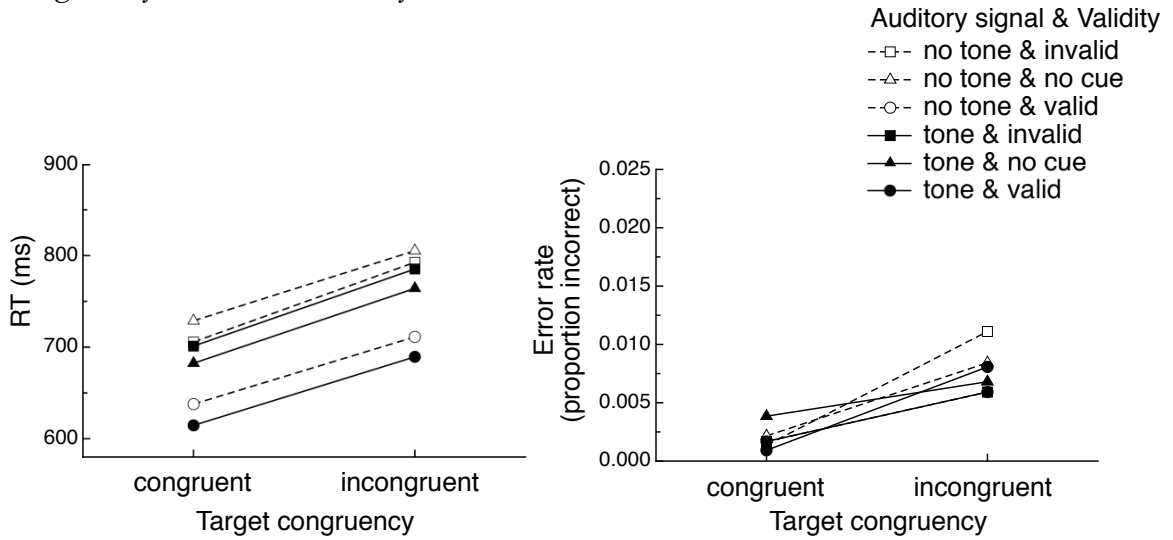


Figure 4.4.1

Mean of each network scores (i.e., difference scores) in RT (top panels) and error rate (bottom panels) for alerting (no cue - double cue), orienting (center cue - spatial cue), and executive (incongruent - congruent) networks in the ANT. The error bars are 95 percent confidence intervals, which can be used to compare scores against zero. Free standing error bars at the top right of each figure are LSDs to compare scores across the sessions.

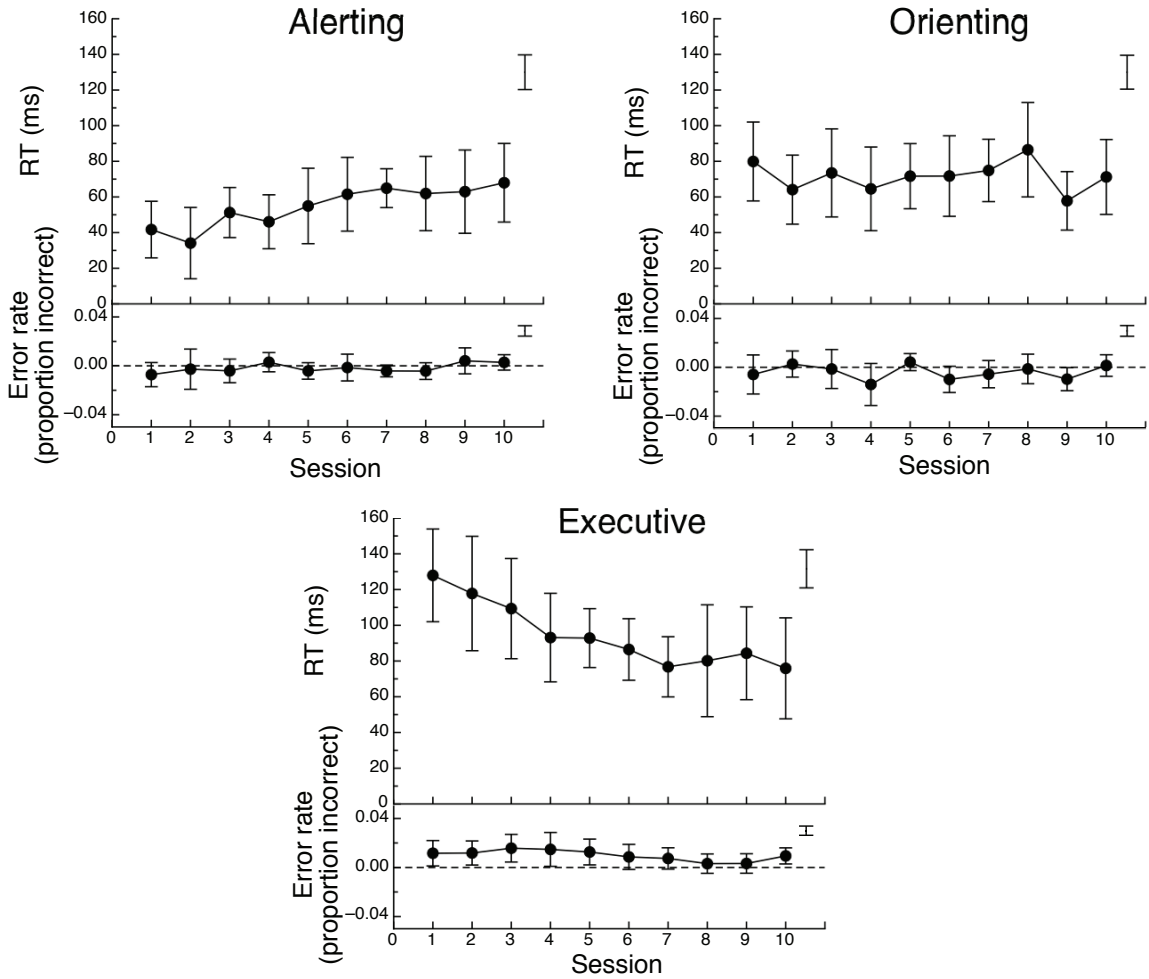


Figure 4.4.2

Mean of each network scores (i.e., difference scores) in RT (top panels) and error rate (bottom panels) for alerting (no tone - tone), orienting (invalid - valid), and executive (incongruent - congruent) networks in the ANT-I. The error bars are 95 percent confidence intervals, which can be used to compare scores against zero. Free standing error bars at the top right of each figure are LSDs to compare scores across the sessions.

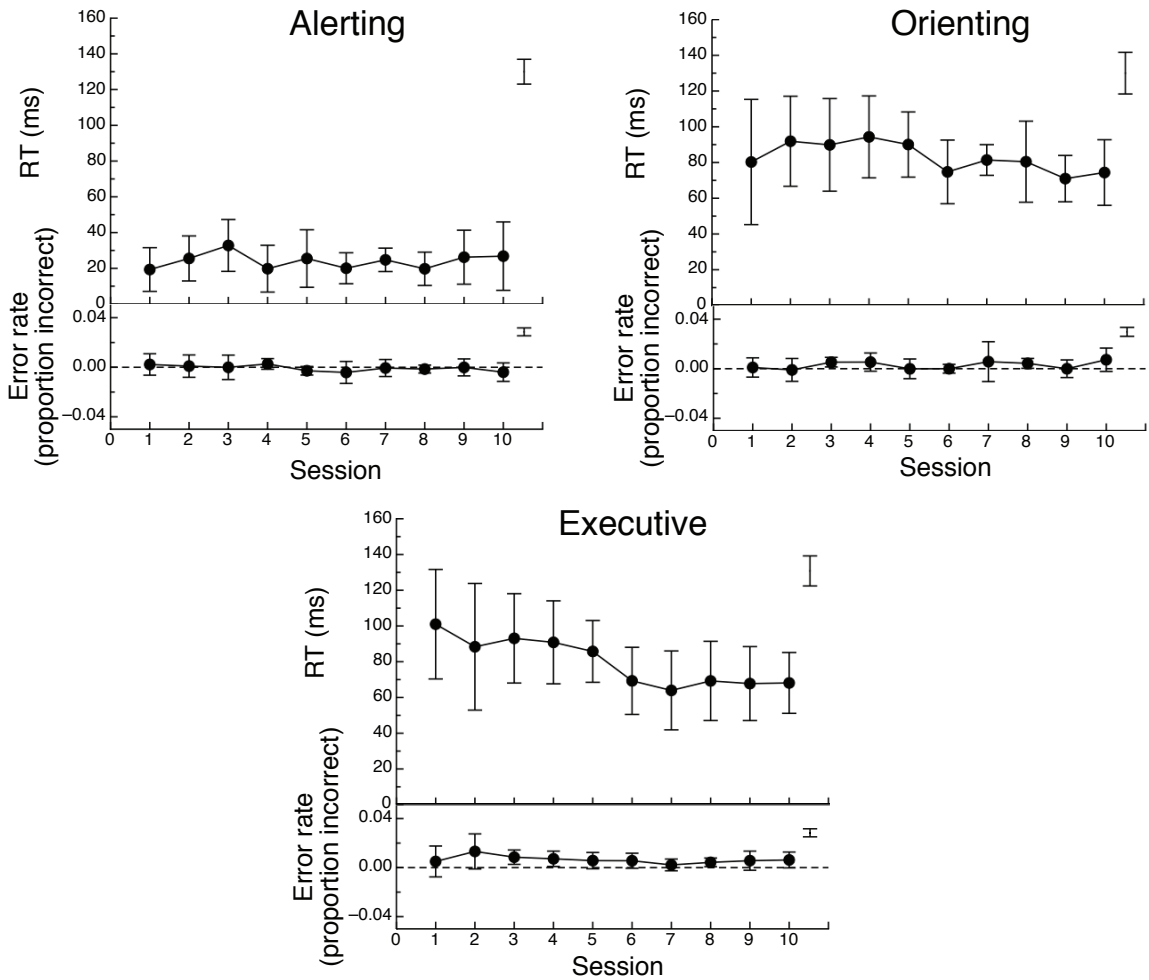


Figure 4.5.1

Reliability of each network scores as a function of number of consecutive sessions included in the analysis (always beginning with Session 1) in the ANT. Reliability was examined using a modified split-half correlation (permutation approach). With a permutation approach, trials to be analyzed were randomly split into two halves 10,000 times. A correlation was computed for each split, and reliability was the mean of the 10,000 correlations. Correlation is significant at the .05 level if $r \geq .64$ (dotted lines) and significant at the .01 level if $r \geq .77$ given $N = 10$.

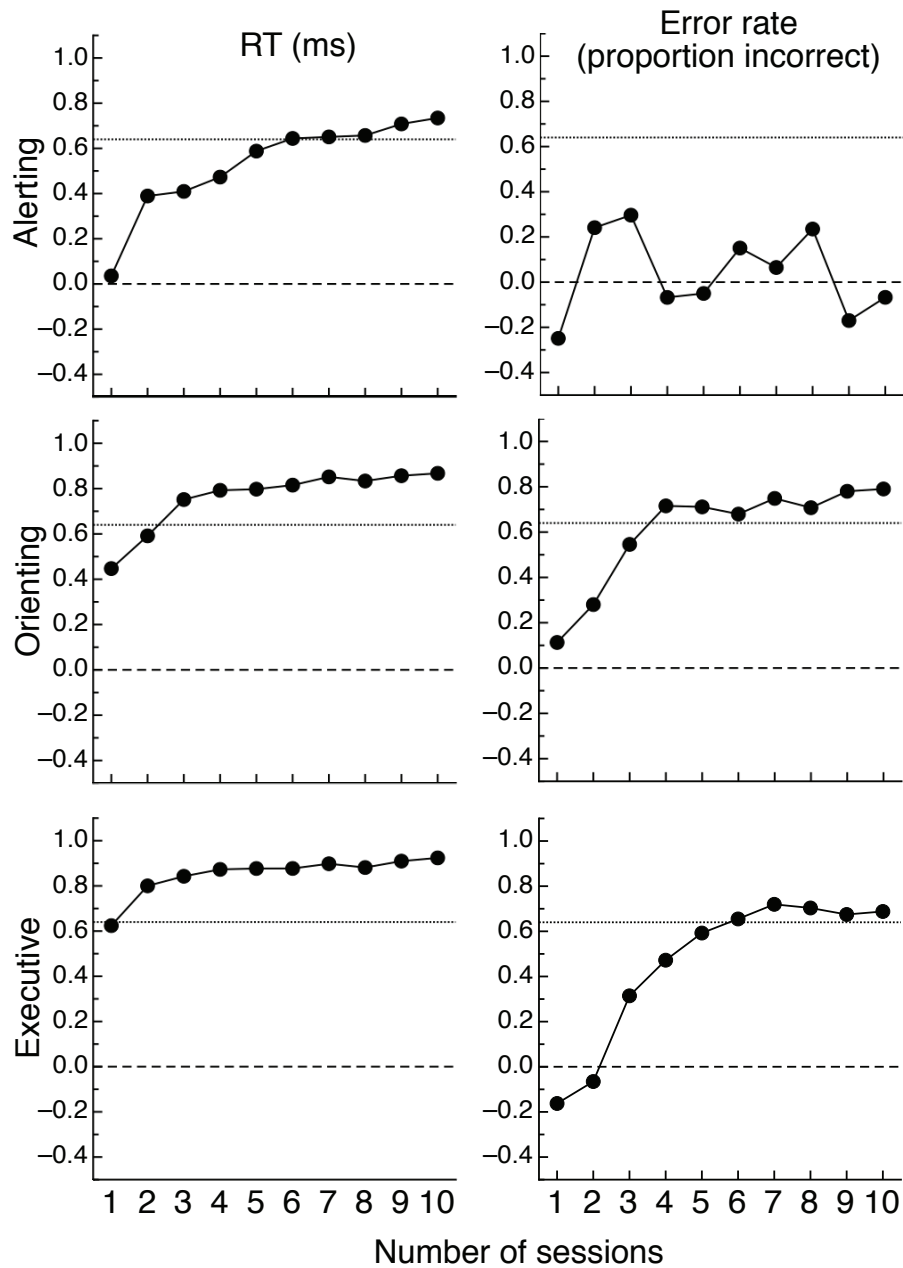


Figure 4.5.2

Reliability of each network scores as a function of number of consecutive sessions included in the analysis (always beginning with Session 1) in the ANT-I. Reliability was examined using a modified split-half correlation (permutation approach). With a permutation approach, trials to be analyzed were randomly split into two halves 10,000 times, a correlation was computed for each split, and reliability was the mean of the 10,000 correlations. Correlation is significant at the .05 level if $r \geq .64$ (dotted lines) and significant at the .01 level if $r \geq .77$ given $N = 10$.

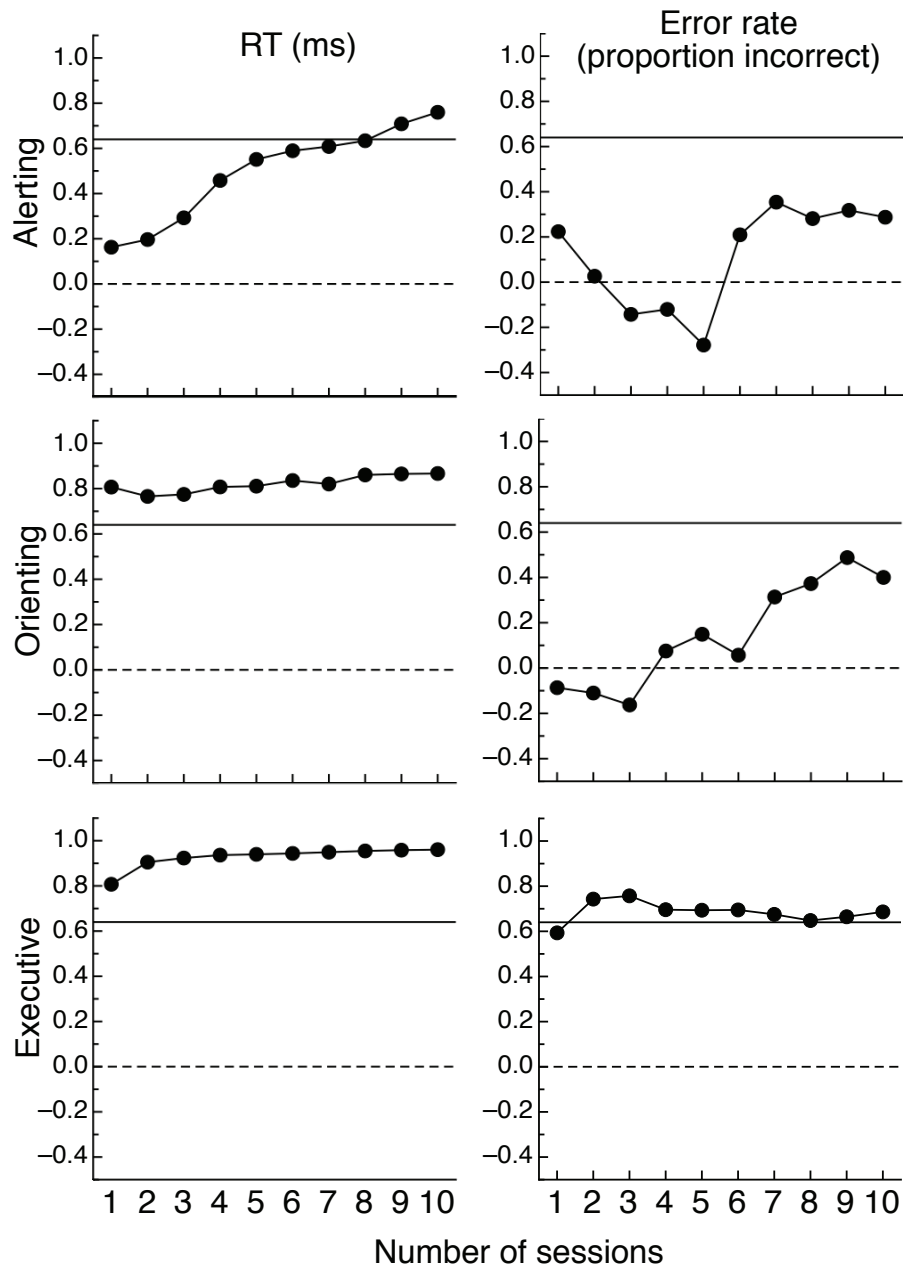


Figure 4.6

RT (upper panels) and error rate (lower panels) with the ANT (left panels) and the ANT-I (right panels). Error bars show half of the least significant difference (LSD) and can be easily interpreted such that non-overlapping bars show significant differences, $p = .05$, within each session.

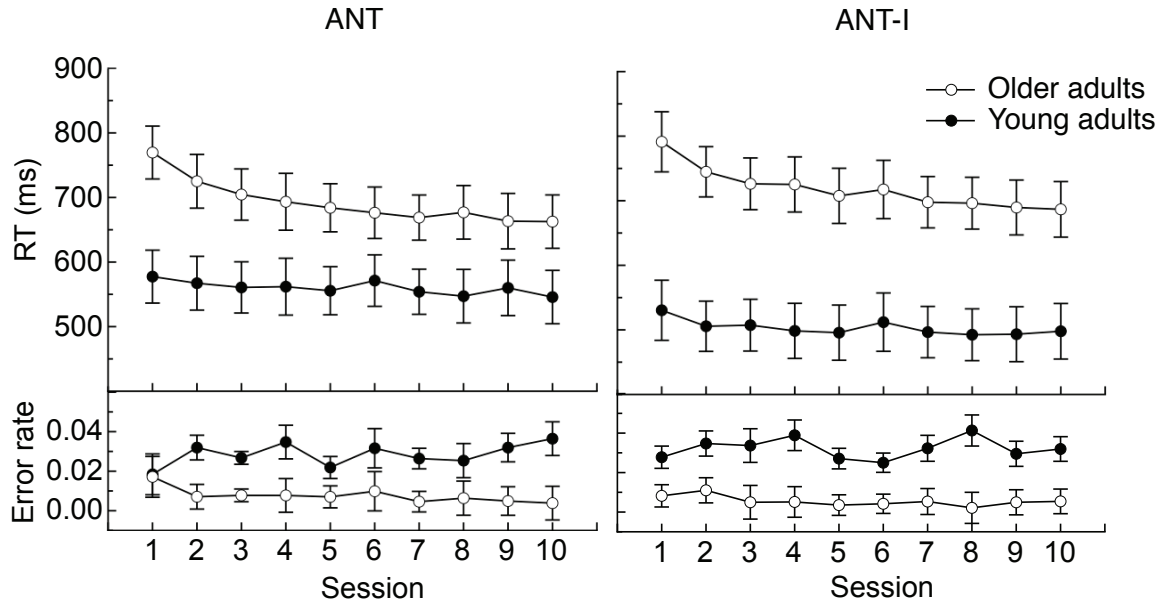
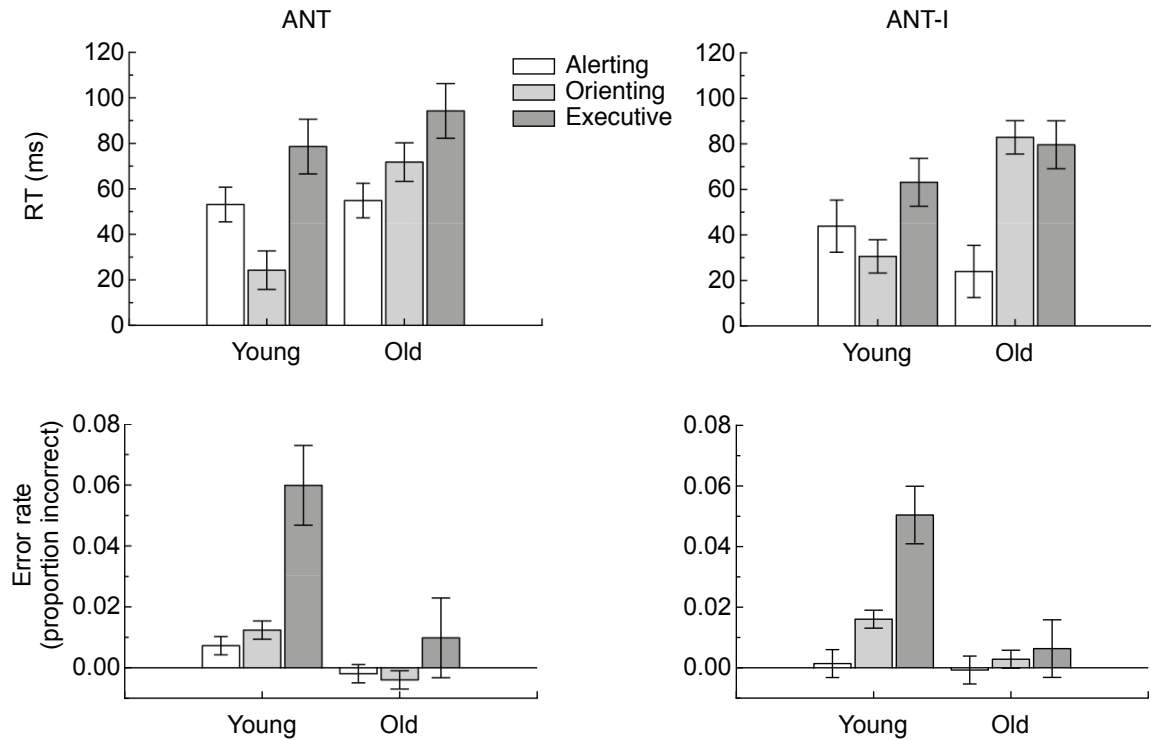


Figure 4.7

Network scores (Sessions 1-10 combined) for the young and the older adults in RT (upper panels) and error rate (lower panels) for the ANT (left panels) and the ANT-I (right panels). Error bars show half of the least significant difference (LSD) and can be easily interpreted such that non-overlapping bars show significant differences, $p = .05$, within each network.



CHAPTER 5:
REPEATED MEASUREMENT OF THE COMPONENTS OF ATTENTION OF
YOUNG CHILDREN
USING THE TWO VERSIONS OF THE ATTENTION NETWORK TEST (ANT):
STABILITY, ISOLABILITY, ROBUSTNESS, AND RELIABILITY

The manuscript based on this study is presented below. It was published (abstract) in 2009 with Canadian Journal of Experimental Psychology-*Revue Canadienne De Psychologie Experimentale*, 63(4), 344, and it was submitted for publication (manuscript) to *Journal of Attention Disorders*. Co-author for this manuscript is Dr. Raymond Klein.

Abstract

Ishigami and Klein (2009b/Chapter 4, 2010/Chapter 3) showed that scores of the three attention networks (alerting, orienting, and executive control) measured with the two versions of the Attention Network Test (ANT: Fan et al., 2002, Callejas et al., 2005) were robust over 10 sessions of repeated testing although learning effects were consistently observed especially in the executive network when young and older adults were tested. The current study replicated their method to examine robustness, stability, reliability and isolability of the networks scores when young children were tested with the child version of the ANT (Rueda et al., 2004). Ten test sessions of the child ANT were administered to 12 young children. The child ANT is essentially a combination of a cueing task and a flanker task. Participants were asked to indicate the direction of a target fish, flanked by distractors, presented either above or below the fixation following different types of visual cue. Network scores were calculated using orthogonal subtractions of performance in selected conditions. Only the alerting network scores remained highly significant after nine previous sessions. The executive network scores showed some practice effects. The reliability of the network scores remained poor regardless of the amount of data.

Introduction

Research on the development of attention during childhood has been done extensively (for a review, see, e.g., Plude, Enns, & Brodeur, 1994). Studies suggest that there are some differences in efficiencies of attention (alerting, orienting, and executive control, Posner & Petersen, 1990) between children and adults.

Alerting

The alerting system maintains task readiness over time (tonic alertness) and activates readiness to respond when a warning signal is presented prior to a target (phasic alertness) (Posner, 1978). Kraut (1976, Experiment 2) found that children (6-7-year-olds) could make use of warning signals; children's responses were faster after novel warning cues than the familiar warning cues, showing alerting effects. Recently, Iarocci, Enns, Randolph, and Burack (2009) reported a general trend across different age groups (5-, 7-, 9-, 24-, 69-, and 81-year old) that responses were slower when there were no warning cues than there were warning cues, showing that phasic alertness did not change significantly with age. However their figure (Figure 3) shows that the difference between the no warning cue trials and the warning cue trials (phasic alertness) was numerically larger for the young children (5-and 7-year old) than the older participants (24-, 59, and 81-year old) (83, 66, 2, 28, 51, and 30 ms, respectively).

Orienting

Orienting involves selecting which channels of input information will receive special processing and is most often studied using competing spatial channels in vision (Posner, 1978). Attention can be directed voluntarily by a central decision (top-down

control) or automatically by a peripheral stimulus (bottom-up control) (Posner, 1980).

The former is endogenous control and the latter is exogenous control of attention.

Perhaps orienting is the most extensively studied attention component among the three networks in the literature of development (e.g., Akhtar & Enns, 1989; Brodeur & Boden,

2000; Brodeur & Enns, 1997; Enns & Brodeur, 1989; Goldberg, Maurer, & Lewis, 2001;

Iarocci et al., 2009; MacPherson, Klein, Moore, 2003; Rueda et al., 2004; Pearson &

Lane, 1990; Wainwright & Bryson, 2002, 2005; Waszak, Li, & Hommel, 2010). These

studies reveal that children as young as 6 years old demonstrate reliable orienting effects

(invalid minus valid conditions) with both types of orienting (Akhtar & Enns, 1989;

Brodeur & Enns, 1997; Enns & Brodeur, 1989; Iarocci et al., 2009; Wainwright &

Bryson, 2002, 2005). The orienting effects seem to decrease during childhood in general

even though results are mixed regarding when the difference between the children and the

adults disappear. For example, Enns and Brodeur (1989) found age differences in the

orienting effects using a Posner's cueing task (1980). For exogenous orienting, larger

orienting effects were found for children (6-9-year olds) than for adults (18-28-year olds)

due to greater costs following the invalid cues rather than greater benefits following the

valid cues (see also Trick & Enns, 1998, but see Akhtar & Enns, 1989 who reported that

both costs and benefits decreased with age), suggesting greater difficulty for children in

disengaging from once attended locations. For endogenous orienting, a similar pattern

was observed: orienting effects for children were numerically larger than for adults. Enns

and Brodeur (1989) did not report what contributed to decreasing effects (costs or

benefits). However, Wainwright and Bryson (2002), using a method similar to that used

by Enns and Brodeur, suggested that decreases in endogenous orienting effects with age were due mainly to decreases in costs (but see Pearson & Lane, 1990). Further, Brodeur and Enns (1997) found with a life span sample that the magnitude of exogenous orienting effects decreased throughout childhood and remained stable after early adulthood into later adulthood (see also Waszak et al., 2010) while such a U-shaped pattern was not observed in magnitude of endogenous orienting effects.

Executive control

Executive control allows for allocation and supervision of resources to assist with non-automated tasks, time-sharing, switching, error monitoring, conflict resolution, etc. (Norman & Shallice, 1986). One of the typical paradigms used to examine conflict resolution is the flanker task (Eriksen & Eriksen, 1974). In this task, filtering out irrelevant information is required to perform the task efficiently (e.g., ignoring flanking distractors in the flanker task). It is often reported that children are distracted by irrelevant information more than adults (Akhtar & Enns, 1989; Enns & Girgus, 1985; Goldberg et al., 2001; Ridderinkhof & van der Molen, 1995; Ridderinkhof, van der Molen, Band, & Bashore, 1997; Waszak et al., 2010). Waszak et al. (2010) reported a U-shaped pattern in a flanker task (Eriksen & Eriksen, 1974) with a life span sample, showing that congruency effects decreased throughout childhood (see also Akhtar & Enns, 1989; Goldberg et al., 2001; Ridderinkhof et al., 1997) but increased in later adulthood.

These studies in the literature examined development of different types of attention separately using different paradigms. Accordingly, it is not easy to examine the

age effects on different components of attention within the same individuals during a short time period. The Attention Network Test (ANT), however, solves these problems. The original Attention Network Test (ANT) was developed by Fan, McCandliss, Sommer, Raz, and Posner (2002) to measure the three attentional networks: alerting, orienting, and executive control (for detailed descriptions on the ANT, see Fan et al., 2002; Ishigami & Klein, 2009a/Chapter 2, 2010/Chapter 3).

Later, Rueda et al. (2004) developed a child version of the ANT (child ANT) to study the development of the three attention networks in children within a single session. The design of the child ANT is similar to the ANT developed by Fan et al. (2002). On each trial, different types of visual cue (center, double, spatial, and no cues: Figure 5.1) are presented, followed by a central target fish, pointing either left or right. The spatial cue is 100% valid regarding the target location. The target fish is often flanked by distracting fish. The task is to indicate the direction of the target fish as quickly and accurately as possible by key pressing. Specific subtraction scores are used to measure the efficiency of three different attention networks (Table 5.1). The efficiencies of the alerting and orienting networks are measured by comparing performance in the different types of cue condition (center, double, spatial, and no cues); the efficiency of the executive network is measured by comparing performance in the different types of target congruency condition (congruent and incongruent). Note that alerting is measured as a difference between the double and the no cue conditions; alerting in the child ANT is phasic. Orienting is measured as a difference between the center cue and the informative spatial cue conditions; orienting here is endogenous.

Rueda et al. (2004) tested 6 to 10-year-olds as well as young adults to examine development of the attention networks. They found no interaction between cue condition and target congruency (Experiments 1-3) and no correlations among the networks in reaction time (RT) (Experiment 3) with the children, suggesting an independence of the three attention networks during childhood. In addition, they found different patterns of development in each network. Children's alerting scores were greater than adults' and the scores decreased up to and beyond age 10. Children's orienting scores did not change between 6-year-olds and adulthood, suggesting early development of orienting. Children's executive scores were greater than adults and their executive scores improved up to age 7 and did not change thereafter.

The child ANT is a simple test, that takes only about 30 minutes to complete (Rueda et al., 2004). As with the adult versions of the ANT (Callejas et al., 2005; Fan et al., 2002), the child ANT can be used in variety of contexts to address a wide range questions about attention. One class of situation for which the child ANT might be useful are those in which repeated testing is required. In fact, Rueda et al. (2005) used the child ANT to examine the effects of educational intervention of 4-year-olds and 7-year-olds on the executive network. The child ANT and electroencephalogram (EEG) recording were administered before and after training (aimed at executive control) or after non-training sessions (control). They reported that the children, especially the 7-year-olds, in the training group showed somewhat better executive function in the child ANT after the training sessions, an effect that was not significant. Thus, the ANT can be and has been used to evaluate effects of training on the components of attention with children.

Accordingly, it is important to understand how performance of each network score changes when the child ANT is repeatedly administered over time.

Despite the use of the child ANT in pre-/post- testing (Rueda et al., 2005), how performance of young children on the three attention networks changes over time with repeated administrations is not known. Ishigami and Klein tested 10 young adults (2010/Chapter 3) and 10 older adults (2009b/Chapter 4) with the ANT and the modified ANT over 10 different sessions. Their methods will provide a model for the present investigation. They reported that scores of the attention components measured by both ANTs remained robust even after 10 sessions although executive network scores with both ANTs decreased with both groups, orienting network scores with the modified ANT decreased with the young adults, and alerting network scores with the ANT increased with the older adults with practice. Both the ANT and the modified ANT were suggested to be a potential tool to measure the attention networks when tested repeatedly.

As mentioned above, the efficiencies of the three attention networks are changing differently through childhood although the exact developmental time course for the different attention components seem to be unclear. Because of this on-going development, it is possible that changes in performance over time in young children may be different from those in young adults and older adults.

The primary objective of the current study was thus to replicate the method of Ishigami and Klein (2009b/Chapter 4, 2010/Chapter 3) and examine the stability, robustness, and reliability of the attention networks derived from the child ANT over repeated testing in young children when the efficiencies of their attention networks are

still developing. In addition, isolability of the network scores was examined. The temporal stability of the scores was examined by Analysis of Variances (ANOVAs) with session as a factor to determine whether the magnitude of the score changed with practice on the task. The robustness of the scores was examined using one-sample *t*-tests to evaluate the significance of each component's score in the different testing sessions. Reliability (or intra-participant stability) was examined by computing for each score the correlation across different combinations of sessions (as will be described in greater detail later). Isolability was examined in two ways: by determining whether there were significant interactions among the measures of the networks in the ANOVAs and whether there were significant correlations among the three networks.

Method

Participants

A total of seventeen children (12 females and 5 males) took part in this experiment. They were recruited from the local community and their parents received \$10.00/session. The participants ranged in age from 4 to 7 years (mean = 5.7 and SD = 1.0). Data of children whose overall correct response rates were less than .85 were excluded, resulting in analyzing the data of twelve children (Table 5.2). As a result, there were at least six correct trials (maximum is 12) in each cell for possible combinations of condition in each session for each child. These children ranged in age from 4 to 7 years (mean = 6.1 and SD = .9). The parents of all children reported the children to be physically and mentally healthy (i.e., not having received a diagnosis of any developmental problems by a health practitioner) and had normal or corrected-to-normal

vision. The parents completed an informed consent form and the study was approved by the Dalhousie Sciences and Humanities Human Research Ethics Board.

Apparatus and Stimuli

We used the program written in Python programming language (<http://www.python.org>) by Michael A. Lawrence. A 17-inch MacBook Pro controlled stimulus presentation and response collection. The child ANT is based on a program written by researchers at the Sackler Institute for Developmental Psychology. Responses were made using keys on the keyboard or buttons on the mouse. Stimuli were a fixation cross (.4° visual angle), asterisk(s) (.52 visual angle), and fish (1.6 visual angle in length, with .21 visual angle distance between fish) pointing either leftward or rightward (Figure 5.1). Fish were yellow outlined in black and presented against a blue background. The fixation cross and the asterisk were black.

Procedure and Design

The sequence of events can be seen in Figure 5.1. The fixation cross was presented for 400-1600 ms in the center of the screen at the beginning of the experiment and remained until the end of a block. Then, the cue was presented for 150 ms. There were four types of cue: center, double, spatial, and no cue (Figure 5.1). In the center cue condition, a cue was presented in the center overlapping with the fixation cross. In the double-cue condition, two cues were presented above and below the fixation cross at the same time. In these conditions, the cues only gave temporal information that the target would be presented shortly. In the spatial cue condition, a cue was presented either above or below the fixation cross. In this condition, the cue gave both the temporal and spatial

information regarding the target location with 100% validity. In the no cue condition, no cue was presented. After 600 ms from the onset of the cue, the target array was presented until the participant responded, but for no longer than 5000 ms. There were three types of target array: congruent, incongruent, and neutral (Figure 5.1). In the congruent condition, the directions of the target fish and the flanking fish were the same. In the incongruent condition, the direction of the target fish and the flanking fish were different. In the neutral condition, the target fish appeared by itself without the flanking fish. The participants' task was to catch the target fish (i.e., indicate the direction of the target fish), pressing the left arrow key on the keyboard or the left button on the mouse when the target fish was swimming leftward or pressing the right arrow key on the keyboard or the right button on the mouse when the target fish was swimming rightward. After participants made a response, the participants received auditory and visual feedback from the computer for 2000 ms both in the practice and the experiential blocks. When a response was correct, the target fish smiled, moving its fin and blowing bubbles. A 'Woo-hoo' sound was presented at the same time. When a response was incorrect, the target fish frowned, rolling its eyes. A buzzer sound was presented at the same time. After the feedback, the target and the flankers disappeared followed by the second fixation period of 1000 ms.

The experiment contained four blocks. A practice block (24 trials) was followed by three experimental blocks (48 trials/block). Cue condition (center, double, spatial, and no cues) and target congruency (neutral, incongruent, and neutral) were orthogonally crossed in the experimental blocks. The 12 possible combinations from each condition

were pseudo-randomly presented so that there were four trials for each combination in a block.

Task Administration

No restrictions were placed on the participants' movements, and the monitor was located approximately 50-60 cm from the participants' eyes. The participants were told that they were going to play a game, in which they would catch swimming fish by pressing the keys on the keyboard or the buttons on the mouse that matched the direction the fish was swimming. The participants placed both index fingers on the keyboard or the mouse, whichever was more comfortable. They were told that sometimes the fish to be caught was swimming by itself and sometimes with its friends, but always swimming in the middle. At the beginning of the first session, the participants were shown pictures of a single fish (neutral condition) and a fish flanked by other fish (congruent and incongruent conditions), swimming leftward and rightward. Using these pictures, the experimenter demonstrated which key or button should be pressed. In addition, the participants were told that it was important to catch the fish as quickly and accurately possible while looking at the fixation cross in the middle of the screen. The experimenter was present throughout the test. The participants started the practice block when the experimenter judged that they clearly understood the task. The participants were individually tested. The participants performed the child ANT in ten sessions, each of which lasted about half an hour. Intervals between two consecutive sessions were not fixed and the mean interval was 9.4 days (SD = 5.8).

Results

For each participant, trials with improper responses (e.g., responses made before the target was presented) or trials with no responses were excluded (4.2%). For each participant, analyses were done twice. The first set of analyses were done using mean RT with different upper cutoffs for each participant. Trials greater than 2.5 SD above their mean RT and trials with RT faster than 200 ms were excluded³³ (3.4 % of the remaining trials). The second set of analyses were done using median RT after excluding trials with RT faster than 200 ms were excluded (.2 % of the remaining total). Because the results with means and medians were almost identical, we will focus on the analysis of mean RT. Mean correct RT and mean error rate were computed and subjected to analyses. Table 5.3 shows the mean RT and error rate for Session 1 and Sessions 1-10 separately, and Figures 5.2.1-2 show mean RT and error rate for target congruency and cue condition as a function of session.

Stability and Isolability of the Network Scores

To allow comparison with the literature (which typically only has one session) analyses were done separately for Session 1 and Sessions 1-10 (all sessions were included). Stability was examined by ANOVAs and isolability was examined by ANOVAs and correlation analyses.

ANOVAs

The mean RT and the mean error rate were submitted to ANOVAs with cue condition (center, spatial, double, and no cues), and target congruency (neutral,

³³ A different set of analyses were done using mean RT with 5000 ms as the upper cutoff for all children. This was done because longer RTs might carry meaningful information. There were occasional differences from the mean RT analyses with the different cutoffs. These will be noted as appropriate.

congruent, and incongruent) as repeated-measures factors (and session (1-10) for the Sessions 1-10 analyses).

Session 1 (Figure 5.3.1).

With RT, the main effects of cue condition, $F(3, 33) = 10.05, p < .0001$, and target congruency, $F(2, 22) = 24.90, p < .00001$, were significant. The interaction between cue condition and target congruency was not significant, $F(6, 66) = 0.95$. The lack of a significant interaction between cue condition and target congruency is consistent with the pattern from the other study of children (Rueda et al., 2004) even though Figure 5.3.1 shows that the congruency effects were numerically greater with the spatial cue and double cue conditions than other cue conditions. For error rate, the main effect of target congruency was significant, $F(2, 22) = 6.52, p < .001$. The main effect of cue condition and its interaction with target congruency were not significant, $F(3, 33) = 1.96, F(6, 66) = .24$, respectively. It can be seen in Figure 5.3.1 that benefits of the spatial cue and the double cue in RT were accompanied by costs in error rate (or costs of the no cue in RT were accompanied by benefits in error rate.).

Sessions 1 - 10 (Figures 5.3.2 & 5.4).

For RT, the main effect of session was significant, $F(9, 99) = 2.32, p < .05$, reflecting that RT decreased in earlier sessions but increased again later. The main effects of cue condition, $F(3, 33) = 64.06, p < .00001$, and target congruency, $F(2, 18) = 17.93, p < .0001$, were significant. It can be seen by comparing Figures 5.3.1 and 5.3.2 that the negative impact of distractors in the presence of peripheral cues (i.e., double and spatial cues) observed in Session 1 seemed to have attenuated. However, this was not

statistically significant³⁴. No other effects were significant³⁵. However, examination of Figure 5.4 shows that there may be learning effects in the executive network in earlier sessions (i.e., there is a dramatic decline in the effect measured in RT between Sessions 1 and 2). For error rate, the main effects of target congruency was significant, $F(2,22) = 36.58, p < .00001$, reflecting that performance in the incongruent condition was more inaccurate than performance in the other two conditions. No other effects were significant.

Correlational analyses

Session 1

Table 5.4.1 shows the correlations among the alerting, orienting, and executive networks, overall RT and error rate. There were no significant correlations among the networks in the analysis with RT and error network scores³⁶, $ps > .05$, consistent with Rueda et al. (2004). Overall RT and the alerting network scores in RT were positively correlated so that slower RT was associated with greater alerting effects with RT³⁷. There were no significant correlations among the networks in the analysis with error rate.

³⁴ A separate ANOVA was run with session (Session 1 and Sessions 6-10), cue condition [no alert (no cue) and peripheral alert (double and spatial cues)] and target congruency (congruent and incongruent) as repeated-measures factors. The three-way interaction was not significant, $F(1, 11) = .11$.

³⁵ When the 5000 ms cutoff was used, the interaction between session and target congruency was significant, $F(18, 198) = 1.70, p < .05$, reflecting that congruency effects reduced in earlier sessions but increased in later sessions.

³⁶ Even though errors are not normally distributed, we report the results with untransformed data because the literature on inter-network correlations has more often than not analyzed them untransformed. However, we did transform the errors (arcsine-transformation) and repeated the correlation analyses. Patterns are similar with the patterns based on the untransformed data.

³⁷ With the 5000 ms cutoff, overall RT and the orienting network scores in RT were negatively correlated so that slower RT was associated with smaller orienting effects. In addition, overall error rate and the executive network scores in RT were negatively correlated so that greater error rate was associated with greater congruency effects.

Overall error rate and the executive network scores in error rate were positively correlated so that higher error rate was associated with greater congruency effects. The null correlations among the network scores in RT were consistent with adults' pattern (Ishigami & Klein, 2009a/Chapter 2, 2009b/Chapter 4, 2010/Chapter 3) and children's pattern (Rueda et al., 2005). However, the lack of significant relationships was not surprising because of the small number of trials included in the analysis of just one session.

Sessions 1-10

There was a significant negative correlation between the orienting and the executive networks; participants with greater orienting effects showed smaller congruency effects³⁸ (Table 5.4.2). Overall RT and the alerting network scores in RT were positively correlated so that slower RT was associated with greater alerting effects in RT. There were no significant correlations among the networks with error network scores, $ps > .05$. Overall error rate and the executive network scores in error rate were positively correlated so that higher error rate was associated with greater congruency effects.

These results should be interpreted with caution due to the large number of relationships examined, the small number of samples, and the low reliability of the network scores (see below).

³⁸ With 5000 ms cutoff, there were no significant correlations in the analysis of the RT network scores, $ps > .05$.

Robustness of the Network Scores

Figure 5.4 summarize scores of each attentional network for RT and error rate as a function of session. To examine robustness of the network scores, one-sample *t*-tests were conducted on each score for each session³⁹.

For the alerting network scores were significantly different from zero in all 10 sessions, *ps.* < .01. These results (see Figure 5.4) demonstrate that the ANT provides a robust index of the alerting network in RT. However, the network scores for the executive network were significantly different from zero only in three sessions (Sessions 1, 3, 4)⁴⁰, and none of the orienting network scores were significantly different from zero. For error rate, none of the alerting and the orienting network scores was significantly different from zero across the sessions. The executive network scores were significantly different from zero in three sessions (Sessions 1, 3, 7), *ps.* < .05.

In addition to *t*-tests, separate ANOVAs were run with cue condition or target congruency as a repeated-measures factor including only relevant conditions for each network (i.e., double and no cue conditions for alerting, center and spatial cue conditions for orienting, and incongruent and congruent conditions for executive control). This analysis was done to examine effects of each network when all the sessions were included. For RT, the main effects of the alerting, orienting, and executive network were significant, $F(1, 11) = 141.493, p < .0000001$; $12.118, p < .01$; $35.610, p < .00001$,

³⁹ Variability (see LSD bars) was large (especially for RT). Different ANOVAs were run using standard deviation (SD) of RT with session as a repeated-measures factor to examine change in variability as a function of session. The main effect of session was not significant for any of the network scores, $F_s < 1.5$, indicating that variability did not change over time.

⁴⁰ With the 5000 ms cutoff, the executive network scores were significantly different from zero in only two sessions (Sessions 1 and 3).

respectively. For error rate, the main effect of the executive network was significant, $F(1, 11) = 37.678, p < .00001$. The main effects of the alerting and the orienting networks were not significant, $F_s(1, 11) < 1$. When all the sessions were included the child participants were quick to respond in the presence of the alerting signals and in the presence of the informative peripheral cue. In addition, they were quick to respond in the presence of the congruent distractors and made more mistakes in the presence of the incongruent distractors.

Reliability of the Network Scores

First, reliability was examined by correlating the first two sessions to allow comparison with Rueda et al. (2004) correlational analyses between Sessions 1 and 2. Then, reliability including different numbers of consecutive sessions was examined using a modified split-half correlation. In this permutation method⁴¹, trials to be analyzed were randomly split into two halves 10,000 times, a correlation was computed for each split, and reliability was the mean of the 10,000 correlations.

With RT, the correlation between Sessions 1 and 2 was significant only for the executive network (Table 5.5). The significant correlation for the executive network is consistent with Rueda et al. (2004). None of the correlations between Sessions 1 and 2 for error rate were significant. Results of the modified split-half reliability analyses as a function of number of consecutive sessions included in the analysis can be seen in Figure 5.5. None of the reliability measures were significant regardless of number of sessions.

⁴¹ We thank Michael A. Lawrence for proving us of R scripts for the modified split-half correlational analyses.

Discussion

The present experiment was conducted to examine, in children, the stability, isolability, robustness, and reliability of the measures of attention network (alerting, orienting, and executive) derived from the child ANT over repeated testing.

Stability: There were learning effects in earlier sessions in the executive network (Figures 5.4). **Isolability:** The network scores were independent of each other for most of the situations. **Robustness:** The child ANT failed to produce a robust index for two (orienting, executive control) of the three attention networks across repeated administrations of the test. The network scores were robust over 10 sessions only with the alerting network scores. **Reliability:** Reliability of the networks were found to be poor regardless of the amount of data included. In addition, examination of the data (Figures 5.3.1 and 5.3.2) shows that the participants were: 1) slow to respond but accurate when there was no warning cue and 2) slow and inaccurate in the presence of distracting incongruent information. In addition, we observed that overall RT increased especially after Session 3, suggesting boredom effects⁴².

Before discussing the results further, it is important to compare our results with Rueda et al. (2004) who tested children with the child ANT (Figure 5.6). Especially relevant to the current study is the Rueda's six-year old group. Despite the variability in performance, Figure 5.6 shows that the orienting and the executive network scores from the Session 1 resemble those from the six-year olds in Rueda et al. Rueda et al. did not

⁴² To explore the possibility of boredom effects a separate ANOVA was run on RT with session and block as repeated-measures factors. The main effect of session was significant as reported above. The main effect of block and its interaction with session were not significant. The results suggest that boredom effects may have occurred across sessions but did not occur across blocks within a session.

report the effect of each network. When all the sessions were included in the current study, the child participants were 1) quick to respond in the presence of the alerting signals, the informative peripheral cue, and the congruent distractors (Figure 5.3.2), consistent with the patterns found in adults (Ishigami & Klein, 2009a/Chapter 2, 2009b/Chapter 4, 2010/Chapter 3).

The child participants could maintain a highly alert state especially when there was a specific warning signal, consistent with Kraut (1976). Further, these alerting effects were robust across multiple sessions. The robustness of the alerting effects after repeated testing is consistent with young and older adults (Ishigami & Klein, 2009b/Chapter 4, 2010/Chapter 3).

The child participants did not necessarily take advantage of the 100% valid spatial cue to orient their attention to the targets when tested in each session in the current study. Note however that their overall performance collapsed across the sessions does reveal a significant difference between the spatial cue and center cue conditions, indicating that they did indeed take advantage of the informative cue, consistent with the adults (Ishigami & Klein, 2009a/Chapter 2, 2009b/Chapter 4, 2010/Chapter 3). Some studies in the literature showed that children could show endogenous cueing effects between 6 and 8 years of age (e.g., Pearson & Lane, 1990; Wainwright & Bryson, 2002). However, a direct comparison with these studies is difficult because the cueing effects in the current study are essentially a ‘cueing benefit’ calculated as a difference score between the 100% valid spatial and the center cue condition. On the other hand, the cueing effects in the literature are typically calculated as a difference between valid and invalid conditions.

Close examination of Figure 5.3.1 shows that the participants in the first session are able to take advantage of the informative cues in the presence of the congruent distractors, but not in the presence of the incongruent distractors⁴³ or in the absence of any distractors. It seems that the benefits of the spatial information is appreciated only when there is an additional aid (i.e., congruent distractors) and focused attention in space is not required.

The child participants showed greatest congruency effects in the presence of the incongruent distractors in the first session. Close examination of Figures 5.2.2 shows that decreased congruency effect between the first 2 sessions are due mainly to decreased RT in the incongruent condition. Thus, the participants might have learned how to ignore irrelevant flanking fish from the first and the second sessions. The same learning pattern was observed in Rueda et al. (2005, see Introduction above) even though the learning effect between the pre- and post-tests for their control group was not statistically significant.

The learning effects in the executive network were also observed with both young and older adults (Ishigami & Klein, 2009b/Chapter 4, 2010/Chapter 3). The learning of the young and the older adults occur gradually over the ten sessions. Despite their learning effects, the executive networks remain robust across the sessions. Unlike the young and the older adults, the learning effects with the children in the current study occurred immediately after the first session to such a degree that there are almost no flanker effects thereafter in each session. Note however that the overall effect when all the sessions were combined was present.

⁴³ *t*-tests were conducted to compare the spatial cue and center cue conditions for the congruent and the incongruent conditions. The difference was significant with RT, $t(11) = -2.248, p < .05$, in the congruent condition. The differences were not significant with RT in the neutral and incongruent conditions.

It was found that each network is generally independent of each other when measured with the child ANT (i.e., no interaction between cue condition and target congruency, and no correlations among the networks). This is consistent with Rueda et al. (2004). However, Figure 5.3.1 shows that the congruency effects were greater in the presence of peripheral cues (i.e., double cue and spatial cue conditions). The greater congruency effects with warning cues without spatial information is typically found with adults (Fan et al., 2002; Ishigami & Klein, 2009a/Chapter 2, 2009b/Chapter 4, 2010/Chapter 3). In addition, we observed a significant correlation between the orienting and the executive networks in RT when all the sessions are included in the analyses, suggesting that the networks may not be independent in all the situations. However, interpreting these patterns must be done with caution because of the relatively low reliability of the scores.

The reliability of all the networks was poor when testing child participants with the child ANT regardless of the number of sessions (i.e., number of trials). This pattern is different from that of the young adults (Ishigami & Klein, 2010/Chapter 3) and older adults (Ishigami & Klein, 2009b/Chapter 4), whose low reliability increased as more data was added. Despite the poor reliability, however, the reliability of the executive network seems to be the better than other networks, consistent with the adults' pattern.

Difficulties in Repeated Testing with Children

It should be noted that participants' overall RT with the child ANT decreased in the first three sessions, showing learning effects, but increased thereafter. This is a different pattern from that observed with the young and older adults with the original

ANT (Ishigami & Klein, 2009b/Chapter 4, 2010/Chapter 3). The child ANT is supposed to be fun and game-like. However, informal observation indicated that the participants became bored quickly, typically by Session 4 or 5. Boredom might affect performance, resulting in unreliable performance, which we observed in the current study. Even though the network scores are difference scores and overall boredom may not affect the difference scores, caution is need in testing young children in multiple occasions (i.e., 4 sessions or more).

Conclusion

The child ANT measures isolable components of attention, namely alerting, orienting, and executive functions, within one session, which takes less than 30 minutes. However, usability of the test with children may be questionable for repeated testing. We observed that scores of the executive network decrease after the first session and that only scores of the alerting network remain robust after 10 sessions. Moreover, their reliability is poor regardless of the number of trials included in the analysis. There may be boredom effects as the sessions progress. This cautions against use of the child ANT in applications that require repeated testing with children.

Table 5.1
Conditions and their levels in the child ANT.

	No cue
Cue condition	Center cue
	Double cue
	Spatial
	Neutral
Target congruency	Congruent
	Incongruent

Subtractions for each network

Alerting	No cue - Double cue
Orienting	Center cue - Spatial cue
Executive	Incongruent - Congruent

Table 5.2

Demographic data for the children removed from the analyses.

Children removed	Age (age in month)	Sex
1	4 (56)	Female
2	4 (59)	Female
3	5 (62)	Male
4	5 (63)	Male
5	6 (79)	Male

Demographic data for the children included in the analyses.

Children included	Age (age in month)	Sex
1	4 (58)	Female
2	5 (70)	Female
3	6 (75)	Female
4	6 (77)	Female
5	6 (78)	Female
6	6 (80)	Female
7	6 (82)	Female
8	6 (83)	Female
9	7 (85)	Female
10	7 (85)	Male
11	7 (85)	Male
12	7 (93)	Female

Table 5.3
Mean RT (ms) and error rate (proportion incorrect).

Session 1

	No cue	Center	Double	Spatial
Congruent	1259 (0.000)	1170 (0.008)	1091 (0.014)	1057 (0.015)
Incongruent	1325 (0.024)	1259 (0.035)	1267 (0.021)	1257 (0.045)
Neutral	1249 (0.007)	1087 (0.035)	1066 (0.023)	1079 (0.035)

Sessions 1-10

	No cue	Center	Double	Spatial
Congruent	1247 (0.018)	1157 (0.013)	1105 (0.010)	1118 (0.015)
Incongruent	1287(0.028)	1229 (0.031)	1154 (0.033)	1184 (0.034)
Neutral	1251 (0.016)	1141 (0.016)	1079 (0.018)	1100 (0.013)

Table 5.4.1

Correlations between attentional networks in mean RT and error rate in the child ANT in Session 1.

RT	Alerting	Orienting	Executive	Overall RT
Orienting	-0.34			
Executive	-0.40	0.17		
Overall RT	0.63*	-0.04	-0.54	
Overall error rate	-0.11	0.23	-0.51	0.14

Error Rate	Alerting	Orienting	Executive
Orienting	0.07		
Executive	-0.03	0.20	
Overall error rate	-0.05	-0.07	0.81*

* $p < .05$

Table 5.4.2

Correlations between attentional networks in mean RT and error rate in the child ANT in Sessions 1-10.

RT (A1)	Alerting	Orienting	Executive	Overall RT
Orienting	0.25			
Executive	-0.19	-0.59*		
Overall RT	0.89*	-0.08	-0.08	
Overall error rate	-0.16	-0.15	-38	0.02

Error Rate	Alerting	Orienting	Executive
Orienting	0.11		
Executive	0.25	-0.11	
Overall error rate	-0.03	-0.07	0.65*

* $p < .05$

Table 5.5

Reliability of the three attention networks from correlational analyses between Sessions 1 and 2 (Rueda et al., 2004 & current study) and from a variation of a split-half correlation analyses including all the sessions.

	Network	Rueda et al.	Sessions 1-2	Sessions 1-10
RT	Alerting	0.37*	0.08	0.16
	Orienting	0.02	-0.09	-0.01
	Executive	0.59*	0.71**	-0.01
Error	Alerting	N/A	-0.31	0.21
	Orienting	N/A	-0.43	0.21
	Executive	N/A	0.20	-0.04

* $p < .05$

** $p < .01$

Figure 5.1

Experimental procedure of the child ANT (Rueda et al., 2004). (I) the four cue conditions. (II) the six target stimuli used in the present experiment. and (III) an example of the procedure; a spatial cue is presented followed by a target (central) fish.

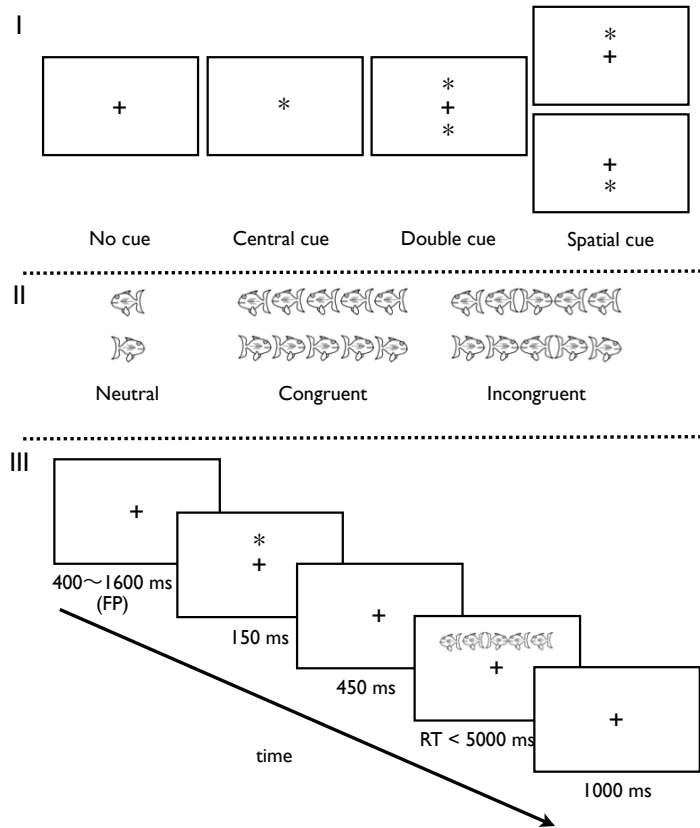


Figure 5.2.1

Mean RT and error rate on the child ANT as a function of cue condition and session.

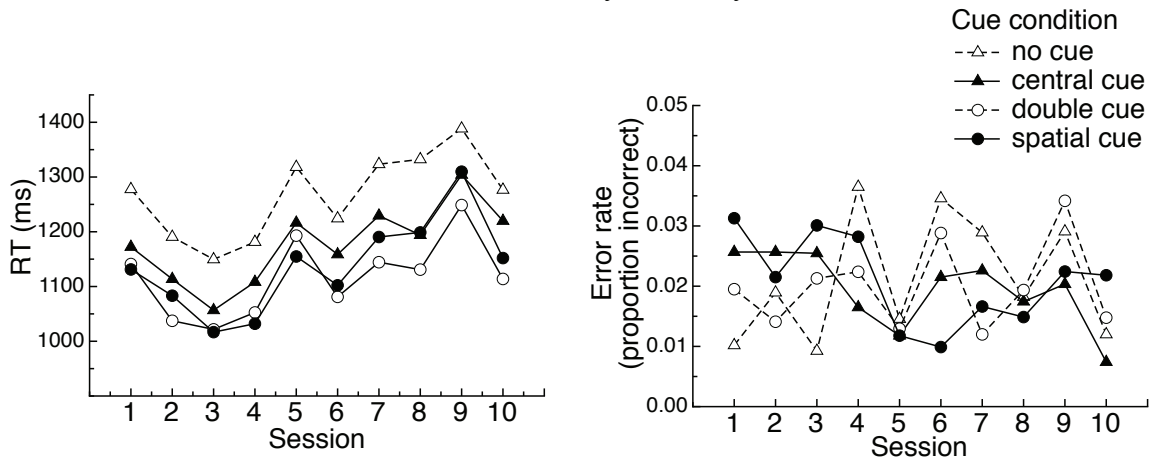
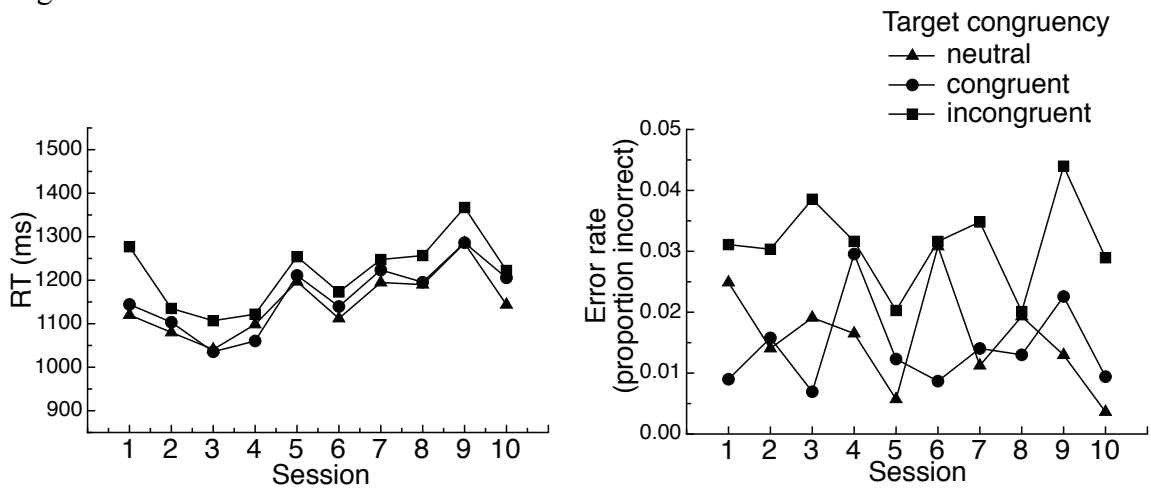


Figure 5.2.2



Mean RT, and error rate on the child ANT as a function of target congruency and session.

Figure 5.3.1

Mean RT and error rate on the child ANT for Session 1 as a function of cue condition and target congruency.

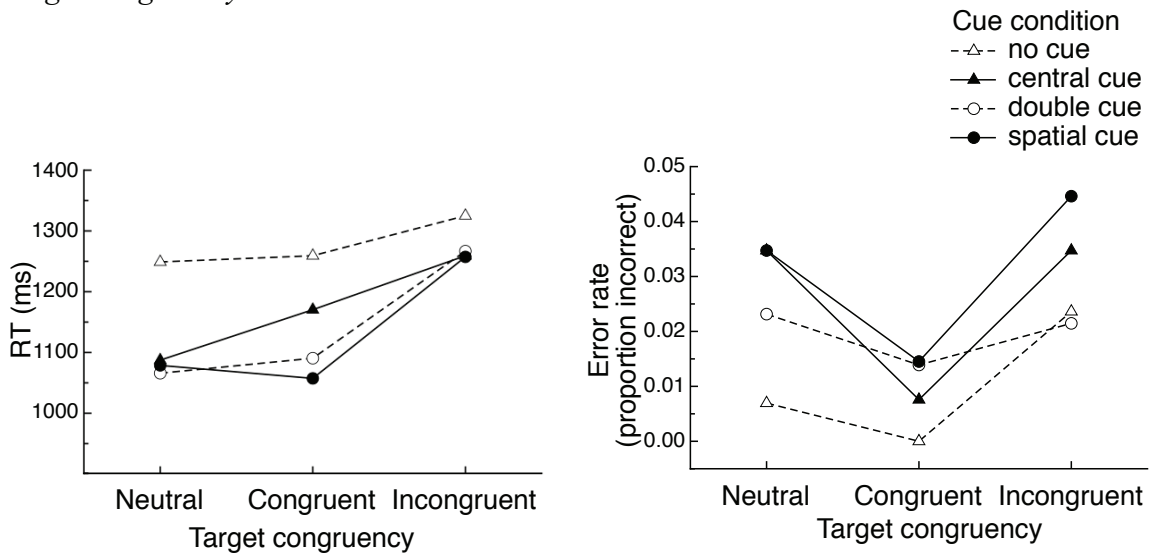


Figure 5.3.2

Mean RT and error rate on the child ANT for Sessions 1-10 as a function of cue condition and target congruency.

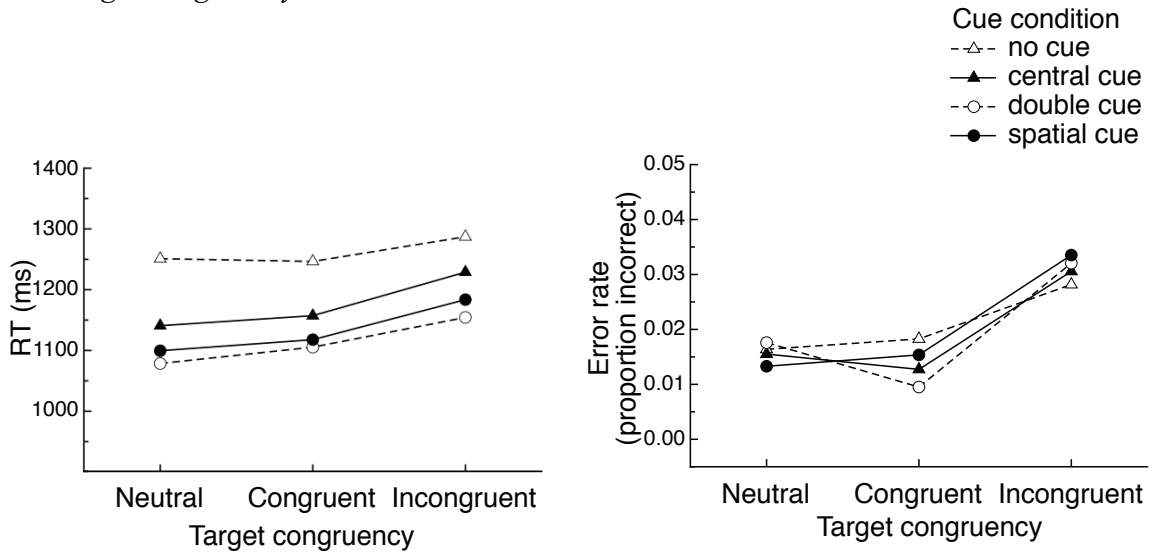


Figure 5.4

Mean of each network scores (i.e., difference scores) based on mean RT for each participant in RT (top panels) and error rate (bottom panels) for alerting (no cue - double cue), orienting (center cue - spatial cue), and executive (incongruent - congruent) networks. The error bars are 95 percent confidence intervals, which can be used to compare scores against zero. Free standing error bars at the top right of each figure are LSDs to compare scores across the sessions.

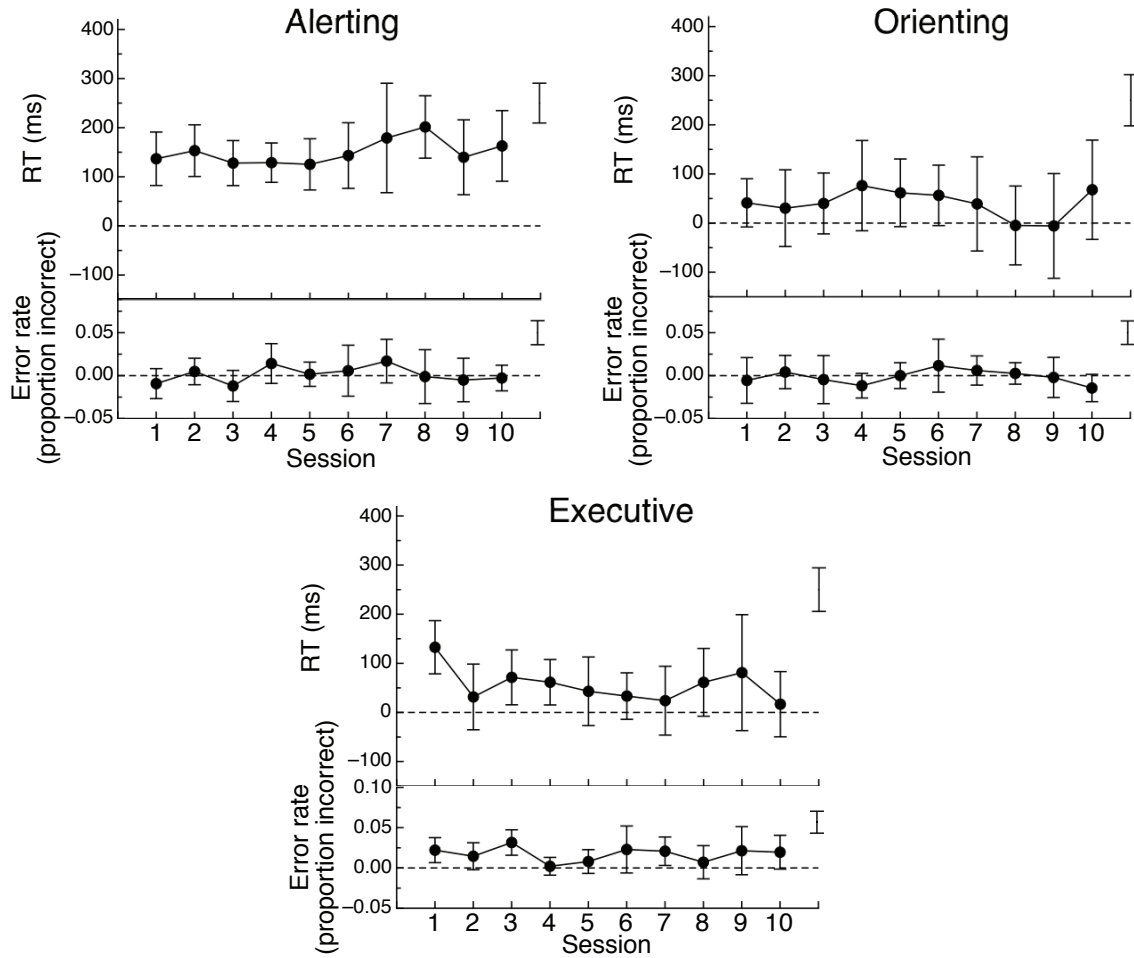


Figure 5.5

Reliability of each network scores as a function of number of consecutive sessions included in the analysis (always beginning with Session 1). Reliability was examined using a modified split-half correlation (permutation approach). With a permutation approach, trials to be analyzed were randomly split into two halves 10,000 times, a correlation was computed for each split, and reliability was the mean of the 10,000 correlations. Correlation is significant at the .05 level if $r \geq .58$ and significant at the .01 level if $r \geq .71$ given $N = 12$.

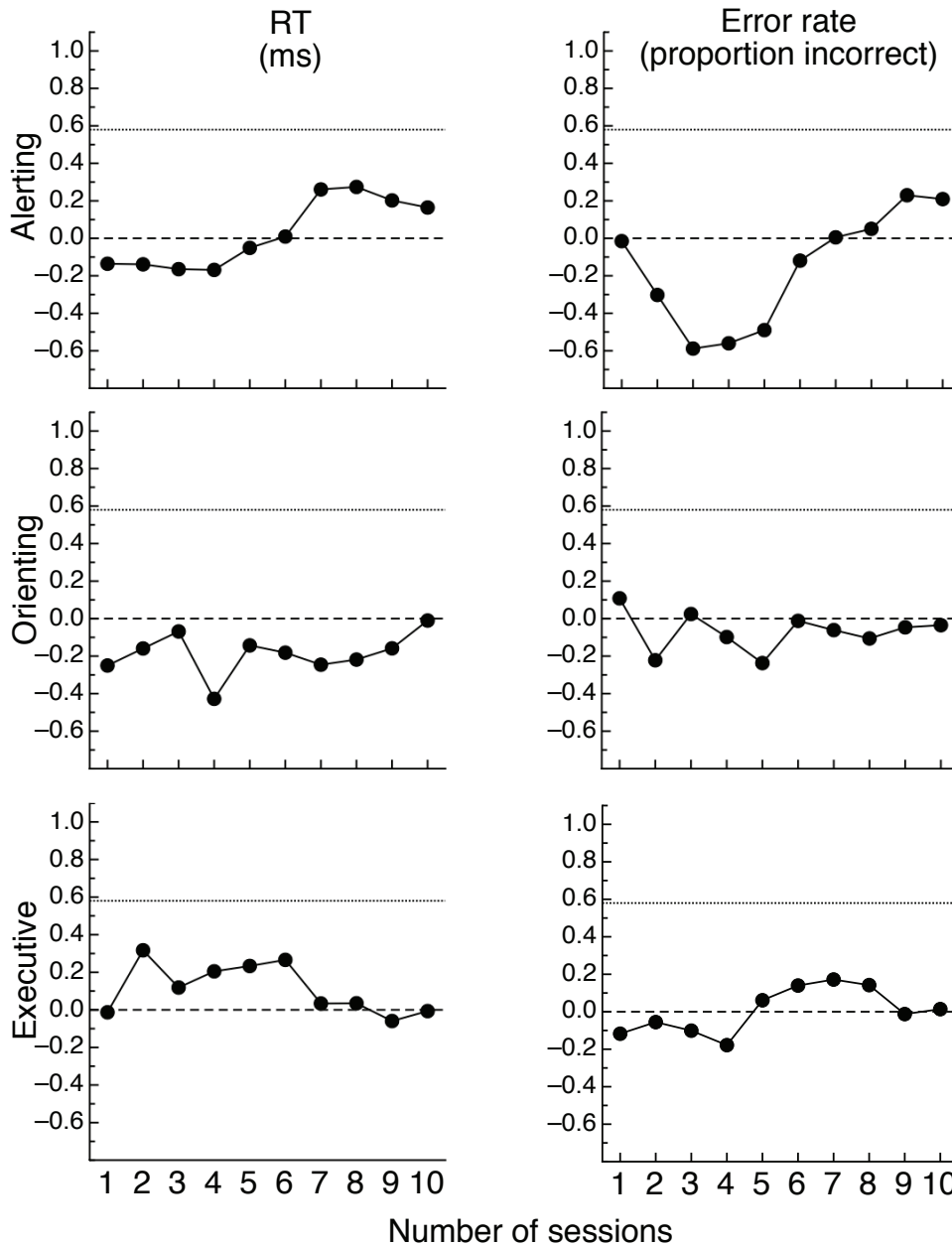
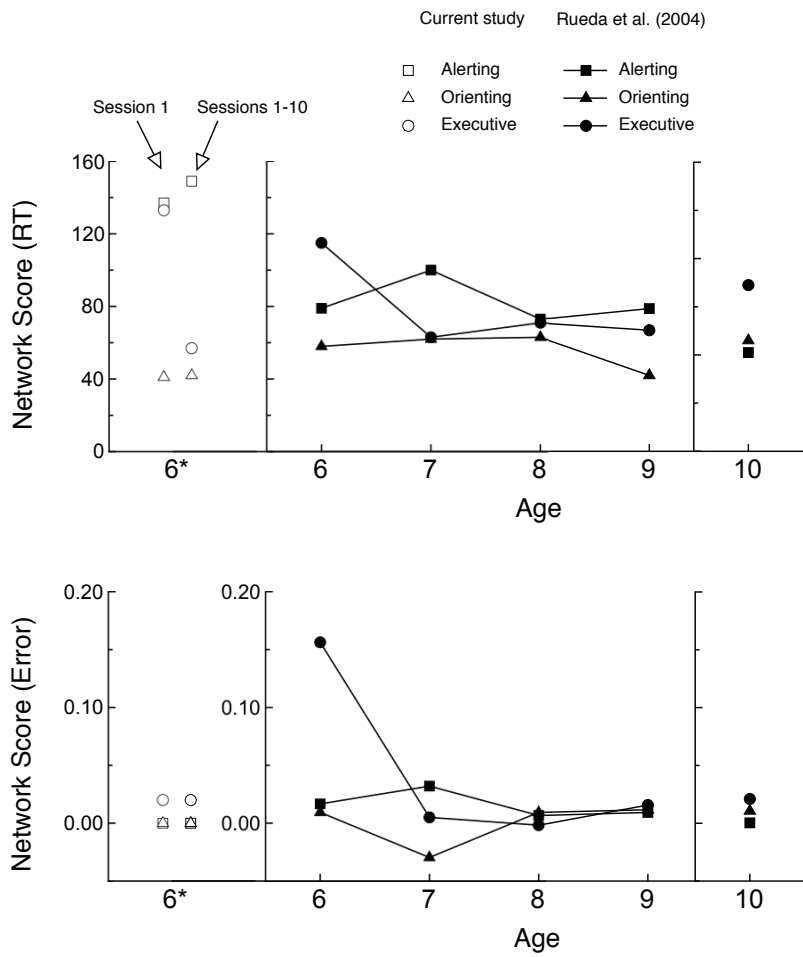


Figure 5.6

Network scores of the current study (Session 1 and Sessions 1-10)* and of the Rueda et al. (2004).



CHAPTER 6: CONCLUSION

Summary

This dissertation examined performance on the Attention Network Test (ANT: Fan, McCandliss, Sommer, Raz, & Posner, 2002, ANT-I (i.e., modified ANT): Callejas, Lupianez, Funes, & Tudela, 2005, child ANT: Rueda et al., 2004) in greater detail for possible application of the ANTs to study individual differences and to use the tests for repeated testing.

The ANTs measure the three components of attention: alerting, orienting, and executive control. Alerting measured with the ANTs is phasic alertness⁴⁴, which is the ability to increase readiness following a signal that indicates that an event will occur very soon. Thus, alerted state is manipulated by presence or absence of a warning signal (visual in the ANT and in the child ANT and auditory in the ANT-I). Larger alerting effects can mean that participants had difficulties in maintaining alerted states without warning signals. Larger alerting effects also mean that participants made efficient use of the warning signals perhaps by making additional efforts (Fan & Posner, 2004).

The ANTs are designed to measure covert orienting because participants are instructed to maintain fixation on the fixation cross. Although all the ANTs use peripheral events to elicit covert orienting, the peripheral cue in the ANT and child ANT is 100% informative about the location of the upcoming target while, in the ANT-I this cues is uninformative about target location. Consequently, there is an endogenous component to

⁴⁴ There are two types of alertness based on tasks to measure them. The other type of alertness is tonic alertness, which is a state of wakefulness or vigilance (sustained attention). In a tonic alertness task, participants are required to maintain alerted state over a period of time and respond to infrequently presented targets. The exact relationship between phasic and tonic alertness is not very clear (Raz & Buhle, 2006).

the orienting measured with the ANT and child ANT while, in contrast, the orienting measured with the ANT-I is purely exogenous. It is generally agreed that the control of endogenous and exogenous orienting is different. Endogenous orienting entails a deliberate effort to attend to the location signified by the cue because targets will appear there. Exogenous orienting is characterized by the capture of attention by an irrelevant peripheral stimulus. Whereas some scholars believe that there is one attentional system (or resources) that are controlled by these two different means, others have argued that different attentional resources are oriented when control is endogenous as opposed to exogenous (e.g., Klein, 2004, 2009). Orienting in the ANT is measured by comparing center cue and spatial cue trials. Note that the spatial cue is an informative cue, but at the same time it is a peripheral cue. Orienting in the ANT is, thus, ‘relatively’ endogenous rather than purely endogenous. On the other hand, orienting in the ANT-I is measured by comparing invalid and valid cue trials. Even though we have asserted that uninformative peripheral cue used in the ANT-I elicits exogenous orienting, this is not completely immune to endogenous influences. It is well known that attentional control settings (ACS) can influence the degree to which a peripheral cue will capture attention (e.g., Ishigami, Klein & Christie, 2009). Therefore differences in orienting measured by the ANT-I could be directly related to the efficacy of the exogenous orienting system or to its modulation by endogenous (ACS) control. Larger orienting effects in both tests may also reflect a difficulty in disengaging from the center cue (ANT and child ANT) and the invalid cue (ANT-I). Larger orienting effects especially with the ANT and the child ANT

may also mean that orienting was more efficient because of additional efforts participants may make (Fan & Posner, 2004).

Executive control with the ANTs may be explained by a supervisory attentional system model which has a frontal lobe locus proposed by Norman and Shallice (1986). According to this model, there is a system responsible for routine and familiar behaviors or tasks, and another system responsible for attentional supervision. The latter system deals with situations involving conflict resolution. Developmentally, executive control is related to self-regulation via the anterior cingulate; children with low conflict effects show less negative emotions (Posner & Rothbart, 2000). Executive control in the ANTs is measured using a flanker task (Eriksen & Eriksen, 1974), which requires resolving conflicts from the incongruent distractors. Thus, executive control in the ANTs is manipulated by congruency of the distractors (congruent or incongruent) to the target. Larger executive effects (congruency effects) implies a greater difficulty in resolving conflicts.

The first goal of this study was to investigate relationships between individual differences in those attention networks measured by the ANT (Fan et al., 2002) and ANT-I (Callejas et al., 2005) and individual differences in absentmindedness measured by the Cognitive Failures Questionnaire (CFQ) (Broadbent, Cooper, Fitzgerald, & Parkers, 1982). The second goal was to investigate stability, robustness, isolability, and reliability of the network scores derived from the ANT, the ANT-I, and the child ANT when tested over multiple sessions with young adults, older adults, and young children. The third goal was to re-examine isolability of the network scores derived from these tests with young

adults, older adults, and young children. The last goal was to examine differences between the ANT and the ANT-I.

Individual differences: ANT (ANT and ANT-I) and CFQ

Greater CFQ scores (e.g., more absentminded) are associated with greater alerting effects in RT with the ANT-I. Here, greater alerting effects can be interpreted as not being able to maintain alerted state without external warning signals. In addition, greater CFQ scores are associated with greater orienting effects in error with the ANT-I. Here greater orienting effects with the ANT-I may be interpreted to reflect greater degree of capture of attention by uninformative peripheral cues. These patterns are consistent; more absentminded people are more reactive to irrelevant external stimuli. On the other hand, greater CFQ scores are associated with smaller orienting effects in error with the ANT. Smaller orienting effects with the ANT can mean that informativeness of the spatial cue is not appreciated. Absentminded people are less able to take advantage of useful information. CFQ scores were not associated with the congruency effects, consistent with Reinholdt-Dunne, Mogg, and Bradley (2009).

Stability of the ANT, the ANT-I, and child ANT

Consistently, learning effects are observed in the executive network in RT regardless of the tests and the tested populations. The young adults and the older adults in the current study seemed to have learned how to ignore irrelevant information gradually; congruency effects were reduced until Session 5. The young children, however, seemed to have learned how to ignore irrelevant information after the first session. The younger adults demonstrated learning effects in the orienting network in RT measured by the

ANT-I. This is consistent with the above observation of learning effects in the executive network; the young participants seemed to have learned how to ignore irrelevant visual cues. The older adults show learning effects in the alerting network in RT measured by the ANT. Here, greater alerting scores can be interpreted as the participant being better able to use the warning cues to prepare for the target's presentation. The importance of the spatial cue was emphasized at the beginning of each session. The older adults might have learned to pay attention to the spatial cue. This might be generalized to other warning cues. However, interpreting this pattern demands caution because learning effects in the orienting network was not observed.

Robustness of the ANT, the ANT-I, and child ANT

For the young adults and the older adults, the network scores remain robust even after nine sessions of practice despite the learning effects in the network scores described above. For the young children, only the alerting network scores remain robust over time. Robustness of the executive network scores diminished due to learning effects. The lack of robustness in the orienting and the executive network scores with the young children in the current study may be due to a small sample size accompanied by the children's variability in performance. However, the results of the current study cautions against the use of the child ANT with children to measure the orienting and the executive network especially when the test is repeatedly administered.

Reliability of the ANT, the ANT-I, and child ANT

For the young adults and the older adults, reliability of RT was greater when more data was added in general. Reliability of the orienting and the executive networks reaches

the level of significance with less data than the alerting network. Different from the adults, reliability of RT is poor for the young children even when more data is added to the analysis. It is possible that the child ANT is still too long for a child to focus their attention to focus on the task even though the length is half of the ANT and the ANT-I. This might cause boredom, lack of motivation, etc, resulting in unreliable performance across the trials. In other words, attention of young children is still inefficient compared with that of young and older adults.

Isolability of the ANT, the ANT-I, and child ANT

For the young adults and the older adults, there is evidence of some dependence among the network score both in RT and error rate. The executive network is reduced by the orienting network; the congruency effects are greater in the invalid than in the valid conditions, consistent with Callejas et al. (2005). This is inconsistent with Fernandez-Duque and Black (2006) who tested young adults, older adults, and Alzheimer's disease (AD) patients with a modified version of the ANT. For the young children, there is no interaction between cue condition and target congruency, indicating that the networks operate independently. These suggest different life span development in the attention networks.

Differences between the ANT and the ANT-I

There are two major differences in the design between the ANT and the ANT-I. One of the differences is that the alerting network is defined by visual cue in the ANT and by the auditory signal in the ANT-I. The other is that the orienting network has both endogenous and exogenous components in the ANT but has only exogenous components

in the ANT-I. Despite these differences, the alerting and the orienting networks scores are not different in magnitude and are related to each other for the young adults. For the older adults, however, these networks are unrelated to each other. One of the reasons for these differences may be differences in the degree to which the participants paid attention to the informative cues in the ANT and ignored the irrelevant cues in the ANT-I. The instructions to pay attention to the spatial cues in the ANT and ignore the visual cues in the ANT-I were emphasized verbally by the experimenter at the beginning of each session for the older adults but the same instructions were given only at the beginning of the first session for the young adults. The patterns the older adults showed may be expected from the design differences.

Future studies

Since Posner and Petersen (1990) introduced the concept of the attention networks (Fan & Posner, 2004; Posner, 1990; Posner & Rothbart, 2007), they have been studied as a unique model to connect the psychological processes of attention with their corresponding anatomical activations in the brain. As a psychometric tool, the ANTs were found to have good validity in terms of its face validity. Especially the orienting and the executive networks are measured using well-established Posner's cueing (1980) and Eriksen's flanker (1974) tasks. Robust network scores (non-zero scores) are observed from all the networks especially when testing adults, suggesting successful manipulations of experimental conditions for the networks.

However, results are mixed regarding discriminant validity or independence of the networks. Non-significant correlations among the networks were observed, especially in

RT (see also Fan et al., 2004), suggesting a good discriminant validity or independence of the networks as distinct concepts. The non-significant correlations when all the sessions are included (i.e., greater reliability) affirm confidence in this independence of the networks (but see MacLeod et al., 2010). However, the statistical interactions among the networks found in the current study and studies in the literature (e.g., Callejas et al., 2005; Fan et al., 2002) suggest some lack of independence among the networks.

The lack of independence may result from shared functions in part between the networks. For example, temporal predictability (i.e., orienting in time) is confounded with both phasic alertness (footnotes #1 and 22) and orienting in space because the SOAs between the warning signal and the target, and the visual cue and the target are fixed in the ANTs. The significant correlation between alerting and orienting that MacLeod et al. (2010) found in their meta-analysis may be due to this shared function. However, Fan et al. (2005) reported that there were no common brain areas for alerting and orienting that were activated together when strict criteria were used (but see Morrison and Foote 1986; Posner 1978). Are alerting and orienting independent of each other if they do not share the temporal predictability? Future studies will be needed to examine the correlation and the interaction between these networks further.

Whether the networks have a good discriminant validity or function independently is one question. Mechanisms of the interactions found among the networks is another question. A possible weakness especially of the ANT-I is that the structure of the test is such that alerting always precedes the other two networks in time. Consequently, alerting can influence orienting and executive control, but not the other

way around. Because of this structure, it may be proper to interpret interactions among the networks in terms of causal relationships. Alerting is placed at the top of a temporal hierarchy that precedes and prepares for the other attentional effects. To determine whether orienting and executive control can influence alerting will require a different experimental design in which alerting follows other networks.

Conclusion

Individual differences in the attention networks measured by the ANT and the ANT-I are related, in a restricted way, to individual differences in absentmindedness measured by the CFQ. The ANT and the ANT-I can be used for applications that require repeated testing with adults - both young and older. Such use is possible because of the robustness of the network scores over time. In other words, the ANTs can validly measure the three attention networks when administered to adults. Reliability of the network scores increases when more data is added, resulting in increased statistical power. Network scores measured by the ANT and the ANT-I are similarly robust when tested over time, but the reliability may be better for the ANT-I than the ANT. For this reason, researchers who are interested in measuring the attention networks might want to use the ANT-I rather than the ANT. Unlike the ANT and the ANT-I, the child ANT needs a caution when used repeatedly with young children because of the lack of the robustness over time for some network scores and poor reliability.

Differences among the young children, the young adults, and the older adults were observed both in the robustness and the reliability of the network scores. Consistent with the literature, efficiency of attention seems to be different across the life span. One

of the factors that may influence the efficiencies could be motivation, which may be related to control for priority (Posner, 1980). Young children may engage in the task only when the task is interesting or only when they feel like participating. Young adults (i.e., students) may be interested in earning credit points and finish the experiment as soon as possible. Older adults may be interested in showing their best performance to experimenters. If these motivational state differences really do characterize (even roughly) the different age groups, then different overall performance and even different patterns of performance on the ANTs across the lifespan may have less to do with fundamental changes in the underlying networks of attention and more to do with these hypothesized motivational state differences. It might be a useful strategy for future researchers interested in lifespan changes in attention to add to their protocols assessments of motivational state.

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Appendix A

The Cognitive Failures Questionnaire (Broadbent, Cooper, FitzGerald & Parkes, 1982)

The following questions are about minor mistakes which everyone makes from time to time, but some of which happen more often than others. We want to know how often these things have happened to you in the past 6 months. Please circle the appropriate number.

		Very often	Quite often	Occasion- ally	Very rarely	Never
1.	Do you read something and find you haven't been thinking about it and must read it again?	4	3	2	1	0
2.	Do you find you forget why you went from one part of the house to the other?	4	3	2	1	0
3.	Do you fail to notice signposts on the road?	4	3	2	1	0
4.	Do you find you confuse right and left when giving directions?	4	3	2	1	0
5.	Do you bump into people?	4	3	2	1	0
6.	Do you find you forget whether you've turned off a light or a fire or locked the door?	4	3	2	1	0
7.	Do you fail to listen to people's names when you are meeting them?	4	3	2	1	0
8.	Do you say something and realize afterwards that it might be taken as insulting?	4	3	2	1	0
9.	Do you fail to hear people speaking to you when you are doing something else?	4	3	2	1	0
10.	Do you lose your temper and regret it?	4	3	2	1	0
11.	Do you leave important letters unanswered for days?	4	3	2	1	0
12.	Do you find you forget which way to turn on a road you know well but rarely use?	4	3	2	1	0
13.	Do you fail to see what you want in a supermarket (although it's there)?	4	3	2	1	0
14.	Do you find yourself suddenly wondering whether you've used a word correctly?	4	3	2	1	0

		Very often	Quite often	Occasionally	Very rarely	Never
15.	Do you have trouble making up your mind?	4	3	2	1	0
16.	Do you find you forget appointments?	4	3	2	1	0
17.	Do you forget where you put something like a newspaper or a book?	4	3	2	1	0
18.	Do you find you accidentally throw away the thing you want and keep what you meant to throw away – as in the example of throwing away the matchbox and putting the used match in your pocket?	4	3	2	1	0
19.	Do you daydream when you ought to be listening to something?	4	3	2	1	0
20.	Do you find you forget people's names?	4	3	2	1	0
21.	Do you start doing one thing at home and get distracted into doing something else (unintentionally)?	4	3	2	1	0
22.	Do you find you can't quite remember something although it's "on the tip of your tongue"?	4	3	2	1	0
23.	Do you find you forget what you came to the shops to buy?	4	3	2	1	0
24.	Do you drop things?	4	3	2	1	0
25.	Do you find you can't think of anything to say?	4	3	2	1	0

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