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RESEARCH ARTICLE

Chronotype and time-of-day influences on the alerting, orienting, and executive components of attention

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Abstract Recent research on attention has identified three separable components, known as *alerting*, *orienting*, and *executive functioning*, which are thought to be subserved by distinct neural networks. Despite systematic investigation into their relatedness to each other and to psychopathology, little is known about how these three networks might be modulated by such factors as time-of-day and chronotype. The present study administered the Attentional Network Test (ANT) and a self-report measure of alertness to 80 participants at 0800, 1200, 1600, and 2000 hours on the same day. Participants were also chronotyped with a morningness/eveningness questionnaire and divided into evening versus morning/neither-type groups; morning chronotypes tend to perform better early in the day, while evening chronotypes show enhanced performance later in the day. The results replicated the lack of any correlations between alerting, orienting, and executive functioning, supporting the independence of these three networks. There was an effect of time-of-day on executive functioning with higher conflict scores at 1200 and 1600 hours for both chronotypes. The efficiency of the orienting system did not change as a function of time-of-day or chronotype. The alerting measure, however, showed an interaction between time-of-day and chronotype such that alerting scores increased only for the morning/neither-type participants in the latter half of the day. There was also an interaction between time-of-day and chronotype for self-reported alertness, such that it increased during the first half of the day for all participants, but then decreased for morning/neither types (only) toward evening. This is the first report to examine changes in the trinity of attentional networks measured by the ANT throughout a normal day in a large group of normal participants, and it encourages more integration between chronobiology and cognitive neuroscience for both theoretical and practical reasons.

Keywords Alertness · Attention · Chronotype · Conflict · Diurnal · Eveningness · Morningness · Time-of-day

Introduction

Current models of attention in cognitive neuroscience postulate three primary functions for attentional mechanisms (i.e., *alerting*, *orienting*, and *executive control*), each presumably corresponding to underlying distinct and independent neural networks (see, e.g., Fan et al. 2002; Fan and Posner 2004; Raz and Buhle 2006). The purpose of the alerting network is to increase and sustain arousal and vigilance so as to better prepare the organism for the detection of forthcoming stimuli (task-specific, phasic alertness) and is thought to be somewhat distinct from intrinsic alertness (non-specific, tonic alertness) (Oken et al. 2006; Parasuraman et al. 1998; Raz and Buhle 2006). The orienting network specializes in selecting specific information from an array of potentially relevant stimuli. The executive component of attention mediates planning, decision making, error detection, conflict resolution, and inhibitory control (Fan et al. 2002; Fan and Posner 2004; Raz and Buhle 2006).

These particular attributes of attention would have been evolutionarily valuable to mammalian survival. That is, in

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response to an environmental stimulus, it would have been beneficial to experience an increase in alertness, to direct processing resources (either overtly or covertly) to the stimulus, and to make a rapid decision concerning response selection. Not surprisingly, recent research has identified heightened activity in specific brain areas when participants perform tasks that are purported to recruit one of these attentional networks. For example, the alerting response has been associated with the frontal and parietal regions of the right hemisphere (Posner and Peterson 1990), although brain areas such as the reticular formation are also involved (Sturm and Willmes 2001). The orienting response is associated with the superior colliculus, frontal eye fields, and superior and temporal parietal areas (Fan et al. 2005), whereas the executive function component of attention involves the anterior cingulate cortex (ACC) and lateral prefrontal cortex (Bush et al. 2000; Fan et al. 2003, 2005; Konishi et al. 2005; MacDonald et al. 2000; Tanji and Hoshi 2008).

Neurochemically, norepinephrine in the locus coeruleus is probably important for the alerting component (Foote et al. 1991; Witte and Marrocco 1997). The cholinergic system, originating in the basal forebrain area, is implicated in orienting (Beane and Marrocco 2004); scopolamine (acetylcholine antagonist) infusions in Rhesus monkeys interfere with covert orienting (Davidson and Marrocco 2000). Middle- and older-aged human participants who had dysfunctional nicotinic receptor genes (CHRNA4) and the apolipoprotein E (APOE-4) gene also had slowed response times on a spatial attention task (Espeseth et al. 2006). Finally, the two brain regions associated with executive function are both input areas from the tegmental dopaminergic system and, accordingly, dopamine (to a large extent based on data from patients with schizophrenia) has been implicated in executive control (see, e.g., Benes 2000). More recently, polymorphism of the dopamine receptor 3 gene (DRD3) (Bombin et al. 2008) and DRD4 gene (Fossella et al. 2002) have also been associated with lower executive functioning in normal participants.

The efficiency of the alerting, orienting, and executive components of attention are frequently measured with the Attentional Network Test (ANT) which was developed by Fan et al. (2002). The ANT combines spatial cuing with a modified version of the flankers task (Eriksen and Eriksen 1974). In brief, participants are required to respond to the stimulus that is presented on the vertical midline (target) while ignoring other stimuli to the left and right (flankers). The flankers can be associated with the same response as the target (congruent), the opposite response (incongruent), or either be omitted or be associated with neither response (neutral). Prior to the final display, advance cues often indicate the possible vertical positions of the target. Some trials include a single cue that always predicts target location (spatial), while other trials include cues at both potential target locations (double), a cue at fixation (center), or no cue at all. Subtraction methods have shown that the alerting (no cue minus double cue), orienting (center cue minus spatial cue) and executive control or conflict components (incongruent minus congruent) are uncorrelated, suggesting independence of their distinct attentional networks (Fan et al. 2002). Twin studies (comparing MZ and DZ twins) have even shown differential heritabilities of each of these networks (Fan et al. 2001).

However, if these three attentional networks are subsumed into an overall attention system, occasional overlap in their functions seems plausible. Negative correlations have sometimes been found between alerting and executive control (e.g., Fossella et al. 2002). In addition, in a non-standard but fine-grained analysis, Dye et al. (2007) found that conflict scores can vary as a function of cue type (see also Callejas et al. 2004, 2005; Fuentes and Campy 2008). Alerting has been described as a "… foundational attentional network, supporting the function of attention globally …" (Raz and Buhle 2006, p. 376). However, current understanding of the relationship between *tonic* alertness-modulating factors (e.g., body temperature or time-of-day) and the attentional networks measured with the ANT is in its infancy. Circadian fluctuations in arousal and performance have been extensively documented (for reviews, see Carrier and Monk 2000; Schmidt et al. 2007), including self-reported alertness (Casagrande et al. 1997; Wright et al. 2002), which is a *tonic*, general type of arousal (Oken et al. 2006) distinct from *task-specific* ANT alerting. Also of relevance is that norepinephrine (Hansen et al. 2001), acetylcholine (Lin et al. 1996), and measures of dopamine (via eyeblinking: Barbato et al. 2000; via homovanillic acid: Posener et al. 1996) all show rhythmic variation across the 24-h day. Diurnal changes in attention, broadly-defined, have been studied, but the tasks employed to measure attention (e.g., pencil and paper letter cancellation), unlike the ANT, are generally not designed to separate the components of attentional systems (Guérin et al. 1991; Kraemer et al. 2000). Clearly, it would be theoretically and practically informative to administer the ANT in a time-of-day fashion.

Early studies (e.g., Kleitman 1963) suggested a strong parallel between task performance and circadian body temperature. However, it is now appreciated that time-of-day effects on task performance can depend on such factors as age (Intons-Peterson et al. 1998), the nature of the cognitive task (Folkard 1983), and especially chronotype (Goldstein et al. 2007). An investigation of time-of-day influences on ANT scores would be incomplete, therefore, without also examining at least chronotype (i.e., morningness/eveningness tendencies), as this may act as a modulator of any time-of-day effects. Morning-type individuals tend to wake up 2 h earlier than evening types (Horne and Ostberg 1977) and have peaks earlier in time (phase advanced) for variables such as melatonin secretion (Martin and Eastman 2002), body temperature (Baehr et al. 2000), and self-reported alertness (Kerkhof et al. 1980; Natale and Cicogna 1996; Smith et al. 2002). Morning- and neither-type individuals also have shorter latencies to fall asleep in response to a forced nap than do evening types (Rosenthal et al. 2001). Most of all, participants tested at their optimal time (e.g., evening types in the evening) tend to perform better on many tasks (i.e., a "synchrony effect") than at their non-optimal times (Horne et al. 1980; May and Hasher 1998; May et al. 2005).

The underlying physiology that differentiates morning- and evening-type individuals is the length of their circadian period or "clock" (tau, τ). Morning-type individuals have shorter values of τ which are actually close to a 24-h period, while evening-type individuals have values of τ that are somewhat longer than 24 h (Daan and Pittendrigh 1976; Duffy et al. 2001). Self-reported alertness/arousal, which correlates with performance on certain tasks (Edwards et al. 2008; Taillard et al. 2006), shows a chronotype effect with morning types reporting more alertness early in the day and evening types more alertness later in the day (Kerkhof et al. 1980; Natale and Cicogna 1996; Smith et al. 2002). The relationship between self-reported alertness and body temperature is equivocal, however, as peaks in self-reported alertness have been reported to occur both earlier (e.g., Folkard 1983; Thayer 1978) and at the same time (e.g., Wright et al. 2002) as the early evening increase in body temperature. As regards performance, Reilly et al. (2007) found that self-reported alertness and temperature both peaked at 2000 hours (in a small sample of athletes), but that simple RT was quickest at 1600 hours, instead; unfortunately, chronotype was not measured in this study.

Given this confusion in the literature, the purpose of the present study was to examine diurnal changes in the efficiency of the alerting, orienting, and executive networks for two groups of participants with differing chronotypes. The working hypothesis was that homeostatic and circadian pressures across the day, in conjunction with the different circadian periods of the chronotypes, would result in systematic variations in the ANT scores. The current study is unique in that it employs a large sample size, administers a well-accepted measure of attention (i.e., the ANT) at four points in time (within subjects, within day), and also includes a standard measure of chronotype.

Method

Participants

A total of 80 undergraduate students from The Pennsylvania State University, Altoona (23 men and 57 women; mean age = 21.6 years; age range = 18–28) volunteered to participate in the present experiment. All participants were in good self-reported physical and mental health with no chronic medical conditions, and all reported having normal or corrected-to-normal visual acuity. Participants were also naive as to the purpose of the experiment and received course credit for participating. The protocol for the present study was approved in advance by the local Institutional Review Board and has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Each participant provided written informed consent before participating.

Morningness/eveningness questionnaire

Chronotype was evaluated using the Horne and Ostberg (1976) morningness/eveningnesss questionnaire (MEQ). The MEQ is the most widely used questionnaire to quantify chronotype. The questionnaire consists of 19 questions and yields scores ranging from 16 to 86 with higher numbers indicated more morning tendencies (16–30 = definite evening type; 31–41 = moderate evening type; 42–58 = neither type; 59–69 = moderate morning type; 70–86 = definite morning type). In younger, college-age populations, MEQ scores tend to be skewed in the direction of evening types (Adan and Natale 2002).

ANT

The standard version of the ANT was employed (available on Jin Fan's website) and presented on Dell computers running Windows Vista with 15-inch color monitors set at a 1,024 × 768 pixel resolution. Participants were seated approximately 65 cm from the monitor. Details of the ANT have been published elsewhere (see Fan et al. 2002, 2005). Briefly, a random fixation period (400–1,600 ms) is followed by either a 100-ms center cue, double cue, spatial cue, or no cue. After another 400 ms, the target (left or right arrow) appears above or below fixation and is flanked by arrows (2 on each side) pointing in the same direction as the target (congruent trials), the opposite direction (incongruent trials), or are not flanked by any additional stimuli (neutral trials). Participants respond to the target by making a compatible button press using the left- and right-pointing arrows on the computer's keyboard.

The alerting score of the ANT is calculated by subtracting mean RT on double-cue trials (which provide temporal information about the target) from mean RT on no-cue trials. The orienting score is obtained by subtracting mean RT on spatial-cue trials (which provide information about target location) from mean RT on center-cue trials. Finally, the conflict score is obtained by subtracting mean RT on congruent trials from mean RT on incongruent trials.

Thayer activation-deactivation checklist

The Thayer activation-deactivation check list (AD-ACL) was used as the self-reported measure for tonic alertness. The AD-ACL uses a visual analog scale (VAS) presented on paper (Thayer 1967, 1978). For each of Thayer's adjectives, an 82-mm line is presented. Participants indicate their current feelings at that moment on the 82 mm bipolar VAS by making a slash mark perpendicular through the VAS line. Responses range from "definitely feel" to "definitely do not feel" going from extreme left to extreme right. The location of the slash mark was later measured in millimeters and assigned a score from 1 to 82. Items were reverse scored so that larger numbers indicated more of the construct. The dimension of general activation (GA) was used in the current study because it was initially shown to vary diurnally by Thayer (1967), and is still a commonly used index of arousal in chronobiological studies (Clodoré et al. 1986). The GA scale contains the adjectives *energetic*, *lively*, *active*, *vigorous*, and *full-of-pep*. The final GA scores could range from 0 to 410. Survey measures of self-reported alertness have been shown to be a valid and reliable way of measuring circadian phase (Folkard et al. 1995). General activation measured with the AD-ACL is an overall measure of tonic arousal, distinct from the more phasic alertness measured with the ANT.

Procedure

Participants arrived at the laboratory shortly before 8:00 am (0800 hours) and were allowed to read a set of written instructions explaining the procedures to be followed with the ANT. Participants were then given 1 block of 26 practice trials with feedback, followed by a block of 96 trials without feedback. All participants thoroughly understood the task after completion of the practice trials. Before beginning the test trials, self-report measures of arousal were obtained using the AD-ACL. Completion of the AD-ACL took less than 1 min. On any given experimental day, groups of two to five participants were tested in the laboratory; however, each participant had his or her own computerized ANT task in a separate cubicle within the laboratory.

The three experimental blocks without feedback consisted of 96 trials each, 2 repetitions of every combination of the 4 cue types, 2 target locations, 2 target directions, and 3 flanker types. Trial types were presented in a pseudorandom order. The participants were instructed to respond to the target stimulus as quickly and as accurately as possible. After each block of 96 trials, participants could take a short break; no participant rested more than approximately 30 s between blocks of trials.

Participants returned to the lab on the same day at 1200, 1600, and 2000 hours for the other three sessions. This design was chosen, in part, because of the logistics associated with testing 80 participants at 4 different times and also to ensure that the length of prior sleep bout would be constant (within subjects) across the 4 sessions. Participants were instructed not to eat lunch just before the noon session so as to avoid a post-prandial drop in body temperature and alertness (Horne et al. 1980). They were also instructed not to consume any caffeine or alcohol before the testing sessions and to avoid taking naps during the day. Although strict control over what activities the participants engaged in during the day was not possible, they were again asked about these same activities after the last session. With only a few exceptions (such as some participants reporting engaging in mild physical activity), few of these internal state-modulating events occurred. The MEQ was administered after the ANT during the noon session. Participants also reported information on what time they went to sleep the previous night and what time they awoke in the morning, which was converted into total length of sleep bout.

Results

The mean chronotype score for the sample was 41.93 with a range from 28 to 62. Using the classification system of Horne and Ostberg (1976), 2 participants were definite evening types, 42 were moderate evening types, 33 were neither types, 3 were moderate morning types, and none were definite morning types, which is a typical chronotype distribution for a young population (Adan and Natale 2002). Participants were then designated as either evening types (E-types: $n = 44$; 34 female) or morning/neither types (MN-types: $n = 36$; 23 were female) for the analyses. The length of previous sleep bout did not differ between the two groups; $P = 0.122$.

Mean response times (RTs) and error rates for each participant were calculated for the 12 different conditions (4 cue types × 3 flanker types) and are presented in Tables 1 and 2. Statistical outliers more than three standard deviations from the mean were removed and, as is typical, the data were collapsed across target direction (left/right arrow) and target location (above/below fixation). As can be seen, the only consistent effects on accuracy were the marked increase in errors on incongruent trials and the moderate decrease in errors with a spatial cue; both $P < 0.001$. More importantly, these effects did not depend on chronotype, time-of-testing, or the combination of these two factors; all $P \geq 0.314$. Therefore, the error data will not be discussed any further, as they would not alter any of the conclusions that are based solely on the mean RTs.

The initial analysis of mean RT concerned the independence of the three component scores that are derived from the ANT—viz., alerting, orienting, and conflict. This was

Table 1 Mean RTs (ms) and error rates (%) for the evening chronotypes as a function of flanker type, cue type, and time-of-testing

	Flanker type						Flanker type					
	Cogruent		Neutral		Incongruent		Cogruent		Neutral		Incongruent	
	RT	Err	RT	Err	RT	Err	RT	Err	RT	Err	RT	Err
Cue type												
	0800 hours						1200 hours					
Spatial	489	0.0	440	0.2	586	3.1	459	0.3	414	0.7	568	3.4
Center	527	0.4	477	0.9	650	4.7	498	0.8	446	0.5	640	6.1
Double	519	0.1	469	1.2	644	7.7	494	0.7	450	1.2	631	6.0
No	566	0.4	526	1.0	671	5.3	538	0.5	509	0.8	661	7.0
	1600 hours						2000 hours					
Spatial	453	0.4	410	0.5	561	2.4	461	0.2	419	0.5	546	2.2
Center	490	0.3	446	0.6	630	5.5	497	0.8	454	0.4	623	4.1
Double	493	0.6	440	0.8	622	5.6	494	0.2	457	0.6	618	4.0
No	533	0.8	510	1.4	652	6.6	540	0.8	519	0.7	644	5.9

Table 2 Mean RTs (ms) and error rates (%) for the morning and neither chronotypes as a function of flanker type, cue type, and time-of-testing

	Flanker type						Flanker type					
	Cogruent		Neutral		Incongruent		Cogruent		Neutral		Incongruent	
	RT	Err	RT	Err	RT	Err	RT	Err	RT	Err	RT	Err
Cue type												
	0800 hours						1200 hours					
Spatial	465	0.2	440	0.2	586	3.1	456	0.2	414	0.7	568	3.4
Center	506	0.1	477	0.9	650	4.7	491	0.0	446	0.5	640	6.1
Double	503	0.3	469	1.2	644	7.7	491	0.0	450	1.2	631	6.0
No	553	0.4	526	1.0	671	5.3	533	0.3	509	0.8	661	7.0
	1600 hours						2000 hours					
Spatial	456	0.6	410	0.5	561	2.4	455	0.2	419	0.5	546	2.2
Center	497	0.4	446	0.6	630	5.5	492	0.4	454	0.4	623	4.1
Double	495	0.1	440	0.8	622	5.6	480	0.2	457	0.6	618	4.0
No	547	0.4	510	1.4	652	6.6	537	0.0	519	0.7	644	5.9

assessed by collapsing the data across time-of-testing and calculating correlations between pairs of components across all of the participants (prior to these calculations, the distributions of the three component scores were all verified as not being different from Normal using the Kolmogorov–Smirnov test; all $P \geq 0.542$). The correlations between alerting and orienting, alerting and conflict, and orienting and conflict were −0.02, 0.01, and −0.04, respectively; all $P \geq 0.710$. Subsequent analyses examining the data at finer scales, such as separately by time-of-testing and/or chronotype found no evidence of significant linear relationships between the components after correcting for multiple tests.

Given the demonstrated independence between the ANT components, the second set of RT analyses consisted of three separate two-way ANOVAs, each examining a single component as a function of both chronotype and time-of-testing. The data employed for these tests are displayed in Fig. 1. Prior to each of these ANOVAs, equality of variance was confirmed using both Levene's test and Box's test of the covariance matrix; all $P \geq 0.198$. However, Mauchly's test produced evidence of a violation of the sphericity assumption (across time-of-testing) for the conflict component; $P = 0.001$. Therefore, in this case, the Huynh–Feldt correction to the degrees of freedom was employed. There was no evidence of non-sphericity for either alerting or orienting; both $P \geq 0.171$.

For the alerting scores (upper panel, Fig. 1), the apparent interaction between chronotype and time-of-testing was confirmed; $F(3,234) = 2.64$, $P = 0.050$. As can be seen, there was no simple main effect of time-of-day on the E-types; $P = 0.877$. However, for the MN-types, the influence of time-of-day was significant; $F(3,129) = 6.19$, $P = 0.001$. Even more, the apparent step-like change between 1200 and 1600 hours was also verified by polynomial contrasts; linear: $t(35) = 3.25$, $P = 0.003$; quadratic: $t(35) = 1.16$, $P = 0.254$; cubic: $t(35) = 2.27$, $P = 0.029$. Overall, there

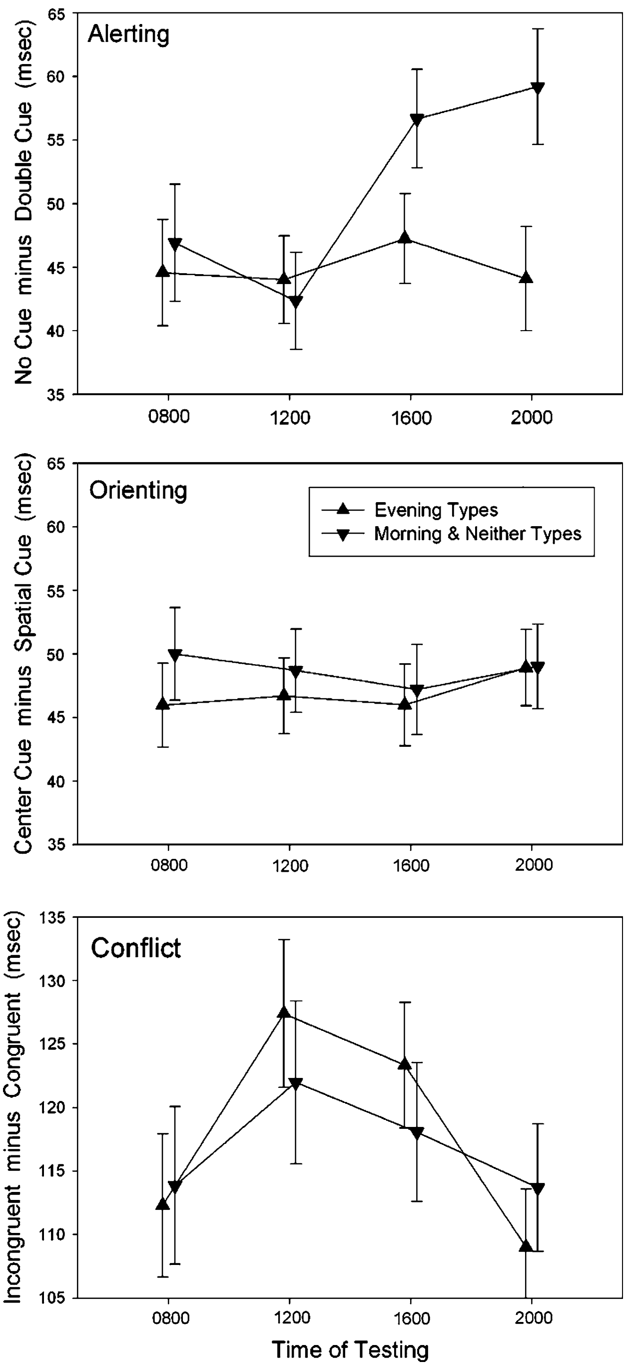

Fig. 1 Alerting, orienting, and conflict scores as a function of time-of-testing and chronotype. *Error bars* indicate the standard errors of the mean

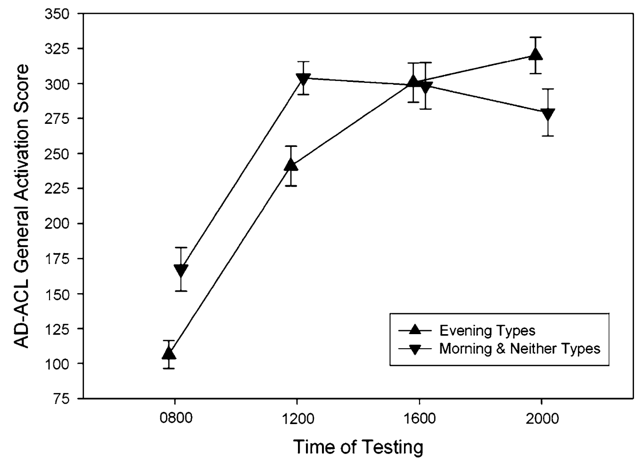

Fig. 2 Self-report general activation scores as a function of time-of-testing and chronotype. *Error bars* indicate the standard errors of the mean

was no main effect of chronotype on the alerting component; $P = 0.128$.

For the orienting scores (middle panel, Fig. 1), there were no main effects or interactions; all $P \geq 0.455$.

For the conflict scores (lower panel, Fig. 1), there was only a main effect of time-of-testing; $F(2.64,206.27) = 6.71$, $P < 0.001$. Neither the main effect of chronotype nor the interaction was reliable; both $P \geq 0.356$. The inverted-U function across time was verified by polynomial contrasts; linear: $t(78) = 0.89$, $P = 0.378$; quadratic: $t(78) = 3.85$, $P < 0.001$; cubic: $t(78) = 1.02$, $P = 0.310$. Additional follow-up tests produced two homogenous subsets: conflict scores at 0800 and 2000 hours did not differ from each other ($P = 0.603$), nor did the scores at 1200 and 1600 hours ($P = 0.206$), but the 0800 and 2000 hours subset had conflict scores that were significantly lower than those for the 1200 and 1600 subset ($P = 0.008$).

Self-reported alertness scores from the Thayer AD-ACL (GA subscale) are presented in Fig. 2 and were also subjected to a two-way ANOVA. Similar to what was found for the alerting scores from the ANT, Mauchly's test was significant, so the Huynh–Feldt correction was again applied. Also similar to before, the interaction between chronotype and time-of-testing was reliable; $F(2.72, 211.86) = 8.56$, $P < 0.001$. In this case, however, the simple main effect of time was significant for both chronotypes; both $P < 0.001$. Separate polynomial contrasts also failed to explicate the interaction (since both curves have roughly the same shape; see Fig. 2), so between-group t tests were conducted at each time of testing. At 0800 and 1200 hours, the MN-types were significantly more alert than the E-types; both $P = 0.001$. At 1600 hours, there was no difference between the groups; $P = 0.915$. At 2000 hours, there was a non-significant trend towards the E-types being more alert than the MN-types; $P = 0.054$. The overall main effect of chronotype was not reliable; $P = 0.123$.

Discussion

This study investigated how the alerting, orienting, and executive function components of attention vary according to both time-of-day and chronotype. Preliminary analysis of the measures of these components derived from the ANT found them to be uncorrelated, suggesting independence for each of the underlying networks. Even more, the pattern of effects for time or day and chronotype differed markedly across these three measures. Alerting scores showed an interaction between time-of-day and chronotype, with increases in the latter half of the day only for the MN-types. In contrast, the orienting component showed no time-of-day or chronotype effects, whereas executive control was lower in the middle of the day for both chronotypes (as demonstrated by higher conflict scores at 1200 and 1600 hours).

Of these findings, perhaps the most striking is the clear modulation by chronotype of the time-of-day changes in the alerting component. The alerting scores from the ANT showed a step-like increase between 1200 and 1600 hours for morning/neither types, but remained constant for evening types. Taken at face value, this increase in the efficiency of the alerting network (from morning to evening) for the MN-types might appear to be counterintuitive. It might also seem to conflict with previous studies of self-reported alertness and chronotype in which morning types report significant decreases in alertness as the day progresses (e.g., Kerkhof et al. 1980; Natale and Cicogna 1996; Smith et al. 2002). Likewise, it might seem to be contrary to our own findings obtained from the GA dimension of the AD-ACL; we found self-reported tonic arousal to increase from 0800 to 1600 for both chronotypes, after which there was a trend for alertness in the MN-types to drop off. These AD-ACL results are consistent with the early evening peak of self-reported arousal found by Reilly et al. (2007) and appear to parallel early evening peaks in body temperature. These trends suggest a temporal dissociation between phasic alertness (ANT alertness) and tonic alertness (GA dimension of the AD-ACL).

When the entire pattern is considered more deeply, especially in light of the distinction between short-term phasic changes and longer-term shifts in tone, the increase in ANT alerting scores for the morning/neither types starting at noon and the typical decrease in their self-reported alertness across the day are not incompatible. As pointed out by Fan and Posner (2004): "Larger alerting numbers generally arise when one group has difficulty in maintaining alertness without a cue" (p. S211). In other words, it is precisely because morning/neither types often fade in their self-reported alertness that they can produce such large alerting scores on the ANT in the latter half of the day: morning/neither types, when tested later in the day, can best take advantage of cues that raise their alertness (even if only momentarily). In contrast, evening types do not lose alertness as the day continues, so their ANT alerting scores do not increase because they do not need (as much) what the cues are providing.

In contrast to this complex modulation of time-of-day effects on alertness by chronotype, we found no evidence of any time-of-day or chronotype influences on the efficiency of the orienting network. This holds even though, presumably, some type of change in underlying arousal was occurring due to circadian and homeostatic processes. These results are consistent with Casagrande et al. (2006) who found that, despite decreases in vigilance stemming from 24 h of wakefulness, orienting mechanisms seemed unaffected during repeated testing with a covert orienting task. Taken together, these results bode well for ANT researchers interested in orienting (such as that evoked by spatial cues), in that neither testing time nor chronotype appears to serve as a potential confound.

Finally, conflict scores were higher in the middle of the day, implying that executive control was lowest at these times. Thus, time-of-day joins with sleep inertia (Matchock and Mordkoff 2007) as a significant determinant of the behavioral consequences of failures of selective attention. Although temperature was not measured in the present study, the inverted-U function for the conflict scores would appear to parallel that for core body temperature (Duffy et al. 1999). However, several other findings argue against temperature as the (sole) mediator of elevated conflict scores and/or depressed executive functioning. Most of all, the acrophase (peak) in human body temperature tends to occur 9–10 h after wake-up time in the early evening hours (see Refinetti 2006, Table 5.3). Sleep-bout length and wake-up time data were collected from the current participants; however, wake-up time data was not presented as almost all participants awoke between 0700 and 0730 hours (to attend their first experimental session). Given this particular and consistent wake-up time, the temperature acrophase should have occurred between 1700 and 1730 hours (see also, Edwards et al. 2007), which is not consistent with the idea that the conflict scores paralleled body temperature (unless elevated conflict scores are phase-advanced with respect to body temperature).

In an attempt to get a better understanding of the present conflict scores, as well as to explore the general idea that the three components of the ANT are independent, an additional analysis was conducted, matching that reported by Dye et al. (2007). Rather than using the standard measure of conflict (which collapses across all four types of cue), separate measures of this component were calculated for each cue type separately. Replicating and extending what was found by Dye et al. (2007), the conflict score for spatial cues was the lowest ($M = 98.2$), intermediate for the no-cue condition ($M = 112.5$), and highest for center and double cues ($M = 130.9$ and 128.9, respectively). This pattern held true for both chronotypes and at all times of day. These findings might appear to raise questions about the separability of the three ANT components, but (as discussed by

Dye et al. 2007) they do not. Instead, these data, when combined with the null correlations between the components help to make the point that overt performance is always dependant on myriad factors, such that RTs (for example) can show statistical interactions when analyzed by ANOVA even when the underlying mental mechanisms are highly distinct. At the same time, the lack of any dependence on time-of-day or chronotype makes that point that these factors do not alter the architecture of the mind; they only serve to influence functioning.

Encouragingly, brain oscillations of different frequencies (e.g., alpha, beta, or gamma) are now starting to be linked to attentional networks (Fan et al. 2007), and diurnal changes in brain electrical activity have been documented (Cacot et al. 1995; Lafrance et al. 2002). Of special relevance is a study by Toth et al. (2007) that compared activity differences between 1400 hour (2:00 p.m.) and 0800 hour (8:00 a.m.) and found increases (lower activity in the afternoon) in the left prefrontal cortex and ACC (theta band), which is consistent with our high conflict scores in the afternoon, assuming the ACC mediates conflict resolution. The results of the present paper suggest that researchers who study neural networks of attention with neuroimaging and psychophysiological tools consider time-of-day and chronotype as potentially relevant variables.

Norepinephrine, acetylcholine, and dopamine do show circadian fluctuations, but fine-grained information is lacking in the human literature due to infrequent sampling times, small sample sizes, the invasiveness associated with obtaining direct brain measures (i.e., dopamine), and the fact that circadian rhythms can be modulated by time of season.

However, concerning norepinephrine, excretion is highest during the active period of the day, typically during late afternoon (1800 hour) (Fibiger et al. 1984; Hansen et al. 2001; Latenkov 1985) and is a measure of sympathetic activity (Pierdomenico et al. 2000). The exact time of the peak varies from study to study, perhaps due to uncontrolled chronobiological factors such as chronotype. The norepinephrine rhythm is also more exogenous (a function of activity level), rather than endogenously generated. Changes in the alerting measure later in the day in the present study appear to further validate norepinephrine as a key chemical involved with alerting. Since norepinephrine is more exogenous and closely associated with activity level, controlling for the activities that research participants engage in before ANT testing may be appropriate. Acetylcholine increases cortical arousal and is also responsible for initiating REM sleep (Baghdoyan et al. 1993). However, muscarinic cholinergic receptor binding is substantially lower during the day than at night (Perry et al. 1977). Concerning dopamine, its metabolic byproduct, homovanillic acid, is measured as a proxy for dopamine. Most studies have found peaks in homovanillic acid in the morning, followed by declines later in the day (Doran et al. 1985; Duncan et al. 2006). Dopamine receptor agonists also increase yawning when administered in the morning (compared to a placebo), but not in the evening (Lal et al. 2000). This pattern is somewhat incompatible with the conflict scores in the present study, characterized by higher conflict scores at 1200 and 1600 than at 0800 and 2000. However, given that the sample was comprised of young college students with presumably phase-delayed rhythms, the trend from 1200–1600 to 2000 hour is consistent with homovanillic studies.

Although investigations into circadian fluctuations of catecholamines are often plagued by small sample sizes and infrequent sampling, it is interesting to note that dopamine and norepinephrine are usually very low at night (0200–0300 hours: Linsell et al. 1985) and highest during the day, especially in late afternoon (Faucheux et al. 1976). If alerting, orienting, and executive functioning are modulated by norepinephrine, acetylcholine, and dopamine, respectively, it would be informative to match assayed concentrations of these neuromodulators (or their metabolites), on an individual basis, to performance on the ANT in a repeated-measures fashion.

Future studies in this area could be improved by employing a larger sample of morning-type individuals and by comparing extreme morning and evening types, perhaps increasing the robustness of this difference (Almirall 1993). Nevertheless, chronotype differences did emerge in the current study despite a weak “manipulation” of this variable. Another limitation of the study was that it employed a time-of-day design. To disentangle circadian and homeostatic factors, forced desynchronization and/or constant–routine paradigms ought to be employed, although these methodologies are both time-consuming and difficult. A time-of-day design cannot distinguish between a buildup of homeostatic sleep pressure and the circadian drive. This limitation, though, is also an advantage in terms of ecological validity. Few humans live according to a 20-h day (as in used under forced desynchronization) or are required to spend a day undergoing a constant routine with no sleep and evenly-spaced iso-caloric meals. Rather, the complete distribution of chronotypes in the population, entrained to a light/dark cycle, performs meaningful tasks that require various aspects of attention throughout most of the day. This is the first report to examine changes in the trinity of attentional networks measured with the ANT throughout a normal day in a group of young, healthy college students. In the real world, individuals do not typically report to work and perform only one short task that requires various components of attention. Rather, attentional resources are relied upon throughout the day, including driving to one’s place of work in the morning and driving home in the evening. Clearly, more research integrating the fields of chronobiology and cognitive neuroscience is needed to thoroughly understand mediating causal mechanisms and to recommend practical strategies for optimizing attentional processing at different times of the day.

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