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Circadian and seasonal variability of resting frontal EEG asymmetry

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ABSTRACT

Asymmetrical frontal cortical activity at resting baseline relates to important aspects of personality and psychopathology. However, some research has failed to replicate these relationships, perhaps because of situational influences. The present research investigates two situational variables, circadian and seasonal variability. These variables affect basal cortisol levels and mood, which have also been found to relate to resting asymmetrical frontal activity. Results of two correlational studies revealed that relative right frontal activity was greatest during fall mornings. These results suggest the importance of assessing time of day (TOD) and time of year (TOY) effects on resting frontal EEG asymmetry, which could reflect circadian and seasonal influences, but also selection effects when participants are free to select among study session times.

Asymmetrical frontal cortical activity at resting baseline is related to important aspects of personality and psychopathology (Coan and Allen, 2004; Harmon-Jones, 2003). For example, greater relative right frontal activity has been related to more depression. Methodological and conceptual questions have emerged about the status of the relationship between individual differences and asymmetrical frontal cortical activity. On the conceptual front, research has compared a valence model with a motivational direction model. In response, research has supported the motivational direction model, which suggests that relative left frontal activity is related to approach motivation, whereas relative right frontal activity is related to withdrawal motivation (Peterson et al., 2008; van Honk and Schutter, 2006). On the methodological front, some have questioned the replicability of the relationship between emotive individual differences and resting, baseline frontal asymmetry (Reid et al., 1998). In response, research has suggested that when examining individual differences in frontal asymmetry, multiple recording sessions are necessary, because only half of the variance in a resting session is due to trait influences (Hagemann et al., 2002, 2005). However, to date, little research has investigated the role of state influences on resting, baseline asymmetrical frontal activity (see Hagemann, 2004). The present research sought to fill this gap.

Two variables present in every study session that may influence baseline asymmetrical frontal activity are time of day (TOD) and time of year (TOY). Yet, all past research has failed to control for these variables. Importantly, both variables have been found to relate to other measures that are related to asymmetrical frontal cortical activity.

The first variable, TOY, influences basal cortisol and mood. With cortisol, levels are highest in fall and winter and lowest in spring (King et al., 2000; Walker et al., 1997). With mood, depression is more likely in fall or winter and remits in spring (Nayyar and Cochrane, 1996). These changes in mood range from normal variations in sadness experienced by most individuals (Nayyar and Cochrane, 1996) to severe variations such as Seasonal Affective Disorder (SAD; e.g. Partonen and Lönnqvist, 1998). Treatment for depression is also more effective in the spring compared to the fall and winter (Wirz-Justice, 2005). More recent research has shown that an individual's seasonality (i.e. seasonal changes in mood and behavior) relates to non-seasonal depression and anxiety, and that even individuals with low to moderate seasonality show a modest increase in depressive symptoms during the winter (Oyane et al., 2008).

Research stemming from seasonal variations of mood has found that TOY also affects the P3 (P300) event-related brain potential (Polich and Geisler, 1991). This research demonstrated that P3 amplitude, which is hypothesized to reflect updating of working memory (Donchin and Coles, 1988; Donchin et al., 1986), is greatest in the spring and summer months (Polich and Geisler, 1991). Recently, P3 amplitude over the frontal cortical regions has been linked to approach sensitivity, suggesting that this ERP may hold similar qualities as EEG alpha power (Peterson et al., 2008). Based on this research and research linking cortisol and mood with TOY, we predicted that season might affect frontal EEG asymmetry.

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More specifically, we predict that relative right frontal activity will be greater in the fall than in the spring.

The second variable present in every study is TOD. Basal cortisol levels follow a circadian rhythm, with higher levels appearing following awakening, and then decreasing throughout the rest of the day, with lowest levels at night (King et al., 2000; Van Cauter, 1989). Also, greater basal cortisol levels have been found to correlate directly with relatively greater right than left frontal cortical activity (Buss et al., 2003; Kalin et al., 1998; Rilling et al., 2001). Importantly, both variables relate to withdrawal motivation. Greater relative right frontal activity is associated with withdrawal-related emotions such as fear (Tomarken et al., 1990), disgust (Davidson et al., 1990), anxiety (Davidson et al., 2000) and depression (Henriques and Davidson, 1991). Similarly, cortisol potentiates fear (Schulkin et al., 1998), and higher levels have been associated with shyness (Schmidt et al., 1997) and anxious depression (Schulkin et al., 1998). Interestingly, mood is also affected by circadian cycles, so that we tend to wake up in a slightly negative mood, but as the day goes on our moods become more positive (Wirz-Justice, 2005). This pattern is consistent with the idea of greater right frontal activity in the mornings developing into greater left frontal activity later in the day. Thus, we predicted that relative right frontal activity at resting baseline might be greatest in the morning. Finally, it is possible that TOD interacts with season to predict relative right frontal activity, such that fall mornings may be associated with greater relative right frontal activity as compared to other times.

As noted above, all past studies on resting frontal asymmetry have not controlled for TOD or season. That is, studies could have been conducted during morning or afternoon only, during fall or spring only, or during all parts of the day and all seasons. Also, in studies conducted during all parts of the day and all seasons, participants could chose when to participate, and researchers did not statistically control for TOD or season. Thus, in the current study, we sought to examine whether these ever-present and freely floating variables may have affected past participants' resting frontal asymmetries by examining the effect of TOD and season on frontal asymmetry. Because we wanted our study to be similar to past studies on resting frontal asymmetry, our participants were not randomly assigned to the TOD or season. What we wanted to examine is whether or not there is variability in resting frontal asymmetry related to TOD and/or TOY (or perhaps participants' selection of such times) that could assist in explaining why some past studies failed to replicate relationships between frontal asymmetry and other individual difference characteristics (for a review, see Coan and Allen, 2004). Of course, this renders the present studies correlational ones (like all past studies on resting baseline frontal asymmetry). Because both circadian rhythms and seasons have been found to influence variables related to asymmetrical frontal cortical activity, we speculated that TOY might moderate the effects of TOD on relative right frontal activity at baseline. Specifically, relative right frontal activity may be at its greatest in fall mornings as compared to fall afternoons and spring mornings and afternoons.

Additionally, it may be that these predicted effects could also be found over the parietal region. Although parietal asymmetry is typically only examined in a comparative nature (e.g. Schaffer, Davidson et al., 1983), research has demonstrated that anxious-depressed individuals evidence greater relative right parieto-temporal activity compared to nonanxious-depressed individuals (Bruder et al., 1997). Therefore, given the associations between anxiety, depression and cortisol (Schulkin et al., 1998), it may be possible that relative right parietal activity will also show circadian and/or seasonal variability.

1. Study 1

1.1. Method

1.1.1. Participants and materials

One hundred and eleven (91 female[1]) introductory psychology students at Texas A&M University (Latitude 30.61N, Longitude −96.32W) participated in exchange for course credit; 33 participants were run in the spring and summer months (12 before 12:00 p.m., 21 after 12:00 p.m.), and 78 were run in the fall and winter months (19 before 12:00 p.m., 59 after 12:00 p.m.)[2].

Seventy-two of the participants completed the revised Interpersonal Adjective Scales (IAS-R; Wiggins et al., 1988) prior to EEG collection. The IAS-R is a broad measure of personality composed of eight variables arranged in a circular ordering around the underlying dimensions of nurturance and dominance. It is made up of single adjectives rated on an eight-point scale ranging from "extremely inaccurate" to "extremely accurate." The 64 items comprise eight scales: Assured-Dominant, Arrogant-Calculating, Cold-hearted, Aloof-Introverted, Unassured-Submissive, Unassuming-Ingenuous, Warm-Agreeable, and Gregarious-Extraverted.

1.1.2. Data collection and reduction

To record EEG, 27 tin electrodes mounted in a stretch-lycra electrode cap (Electro-Cap, Eaton, OH) were placed on the participant's head. The ground electrode was mounted in the cap on the mid-line between the frontal pole and the frontal site. The reference electrode was placed on the left ear, and data were also acquired from an electrode on the right ear, so that an off-line, averaged ears' reference could be computed. All electrode impedances were under 5000 Ω, and homologous sites were within 1000 Ω of each other. Vertical and horizontal eye movements (EOG) were also recorded to facilitate artifact correction of the EEG. EEG and EOG were amplified (an analog 60 Hz notch filter was enabled) with Neuroscan Synamps (El Paso, TX), bandpass filtered (0.1–100 Hz) and digitized at 500 Hz. Four minutes of resting data were acquired; 2 min eyes open (O) and 2 min eyes closed (C). Two sequences were used, O–C–C–O and C–O–O–C, and they alternated by participant.

Following data acquisition, the signals were visually scored and portions of the data that contained artifacts were removed. Then, a regression-based eye movement correction was applied (Semlitsch et al., 1986) after which the data were again visually inspected, to insure that proper correction was done. All epochs 1.024 s in duration were extracted through a Hamming window. A fast Fourier transform was used to calculate the power spectra, which were averaged across epochs of each resting minute. Total power within the alpha band (8–13 Hz) was obtained. Asymmetry indexes were created for homologous frontal sites (F3/4, F7/8) and parietal sites (P3/4; for comparison purposes) by taking natural log right minus natural log left. Because alpha power is inversely related to cortical activity, higher asymmetry scores indicate greater relative left than right activation (Davidson et al., 2000).

2. Results

To examine the effect of TOD and TOY on resting asymmetry, both variables were centered and entered into a regression

[1] For both studies, additional analyses were conducted in which sex of participant was included as a predictor of resting asymmetry. No significant Sex × TOD × TOY interactions were found ($ps > .26$), and all TOD × TOY interactions remained significant ($ps < .05$). Also, in both studies, after baseline EEG data were collected, participants performed one of four separate studies not relevant to the present concerns; most of those data are currently being analyzed but data from one study is published (Peterson et al., 2008).

[2] Breakdown of participants run by month: March, 11; April, 10; May, 3; June, 5; July, 2; August, 2; September, 29; October, 33; November, 15; December, 1.

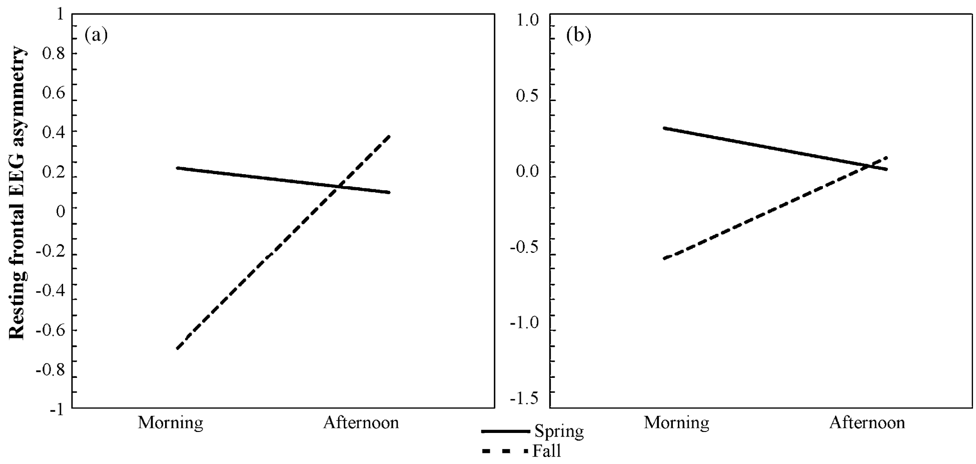

Fig. 1. (a) Study 1: Time of Day × Time of Year interaction predicts resting mid-frontal asymmetry and (b) Study 1: Time of Day × Time of Year interaction predicts resting lateral frontal asymmetry (plotted using guidelines by Aiken and West (1991) and thus values are estimates). Lower asymmetry scores indicate greater relative right than left cortical activity.

equation with their interaction (Aiken and West, 1991)[3]. TOD was entered in military time, so that greater values indicated later periods of the day. Because experiments were conducted from March to December, earlier dates indicate spring/summer, while later dates indicate fall/winter.

For relative right mid-frontal activity (F43), the main effect of TOY on resting frontal EEG asymmetry was marginally significant, $\beta = -.17$, $R^2 = .03$, $t(107) = 1.9$, $p < .06$. This effect suggested that relative right mid-frontal activity was greatest in the fall. A main effect of TOD also emerged; relative right mid-frontal activity was greatest in the morning, $\beta = .25$, $R^2 = .07$, $t(107) = 2.8$, $p < .01$. Furthermore, TOD and TOY interactively predicted mid-frontal asymmetry (F43), $\beta = .32$, $R^2 = .10$, $t(107) = 3.5$, $p < .001$. As shown in Fig. 1a, in the fall, relative right mid-frontal activity was greater in the morning compared to afternoon, $t(107) = 5.4$, $p < .001$. In the spring, mid-frontal activity did not vary by TOD, $p > .53$.

Lateral frontal asymmetry (F87) also produced a main effect of TOY, $\beta = -.21$, $R^2 = .05$, $t(107) = 2.3$, $p < .05$, so that relative right lateral frontal activity was greatest during the fall. Additionally, there was a TOD × TOY interaction, $\beta = .25$, $R^2 = .06$, $t(107) = 2.7$, $p < .01$. The slope of the regression line for fall was marginally significant, $t(107) = 1.62$, $p = .11$, so that relative right lateral frontal cortical activity was greatest in the morning (see Fig. 1b). Lateral frontal asymmetry did not vary by TOD in the spring, $p > .51$. No main effect of TOD occurred, $p > .25$, and no significant effects were found for parietal asymmetry, βs $< .04$, $R^2 < .002$, $t(107)$s $< .46$, ps $> .25$[3].

To further examine the interactive effects of TOD and TOY on mid- and lateral frontal asymmetry, we conducted a planned comparison in which fall mornings were coded as 3 and the other three conditions were coded as -1. Indeed, relative right frontal cortical activity was significantly greater during fall mornings compared to fall afternoons, spring mornings, and spring afternoons, $\beta = -.31$, $R^2 = .10$, $t(109) = -3.5$, $p < .001$ and $\beta = -.20$, $R^2 = .04$, $t(109) = -2.1$, $p < .05$, for mid-frontal and lateral frontal regions, respectively.

Because our goal was to examine these effects naturally (that is, we did not assign participants to a time or season) and thus it is possible that self-selection affected these results, we examined various personality variables in relation to the TOD and TOY effects. First, to examine whether personality differences varied by TOD and TOY, we conducted regressions like the above in which TOD, TOY, and their interaction were entered as predictors of each of the IAS-R subscales. There was a main effect of TOY on unassuming-submissive, so that participants run in the spring were more submissive, $\beta = -.35$, $R^2 = .13$, $t(68) = -3.09$, $p < .01$ (all other TOY main effects ps $> .20$). A main effect of TOD on coldheartedness revealed that participants run in the afternoon were more coldhearted, $\beta = .36$, $R^2 = .14$, $t(68) = 3.24$, $p < .01$ (all other TOD main effects ps $> .16$). Finally, TOD × TOY significantly predicted arrogant-calculating, $\beta = -.33$, $R^2 = .12$, $t(68) = -2.93$, $p < .01$, but neither regression slope was significant, ps $> .64$ (all other TOD × TOY interactions ps $> .15$).

To further examine whether these individual differences in personality affected variations in frontal asymmetry, each of the IAS-R subscales was independently entered as a control variable into the TOD × TOY regression. When predicting mid-frontal and lateral frontal asymmetry, all TOD × TOY interactions remained significant (βs $> .23$, $R^2 > .06$, $t(67)$s > 2.1, ps $< .05$).

3. Discussion

Given that about half of the variance in resting, baseline frontal asymmetry can be attributed to situational factors (Hagemann et al., 2005), these results suggest that TOD and TOY interactively accounted for approximately 12–20% of the state-like variance. Independently, TOD accounted for between 10 and 12% of the variance, while TOY accounted for about 8%. These effect sizes are moderate (Cohen, 1988) and are comparable to those of depression and anxiety (Thibodeau et al., 2006).

The lack of circadian variations of frontal asymmetry in the spring is inconsistent with some previous research on cortisol (King et al., 2000) but consistent with research showing that spring often causes a reduction in sadness and depression. This could explain why we found no relationships between TOD and frontal asymmetry in the spring, yet found significant relationships in the fall. In other words, resting frontal asymmetry may be predicted by basal cortisol as well as other state variables such as mood or motivation that may vary with seasons.

Because of the novelty of the effects observed in Study 1, we sought to examine whether they would replicate in a second study.

[3] For both studies, TOY and TOD were not associated. Also, all assumptions for regression were met, except TOY was slightly non-normally distributed; it tended toward bi-modal. We thus conducted regression analyses for each study in which TOY (effect coded for first half of the year and second half of the year), TOD (centered), and their interaction predicted each of the asymmetry indexes. All interactions remained significant [Study 1: βs $> .27$, $t(107)$s > 2.8, ps $< .01$; Study 2: $\beta = .29$, $t(61) = 2.1$, $p < .05$]. The interactions predicting parietal asymmetry remained nonsignificant [Study 1: $\beta = -.13$, $t(107) = -1.3$, $p > .19$; Study 2: $\beta = -.08$, $t(61) = -.60$, $p > .54$].

In addition, although Study 1's personality data suggested that individual differences in eight personality characteristics did not explain the correlation between TOD, TOY, and resting baseline frontal asymmetry, we sought to further address whether self-selection may explain our results by examining trait behavioral inhibition and behavioral activation sensitivities (BIS/BAS).

4. Study 2

4.1. Method

4.1.1. Participants and materials

Sixty-five (27 female) introductory psychology students at Texas A&M University participated in exchange for course credit; 21 participants were run in the spring and summer months (8 before 12:00 p.m., 13 after 12:00 p.m.), and 44 were run in the fall and winter months (15 before 12:00 p.m., 29 after 12:00 p.m.)[4].

All subjects completed Carver and White (1994) BIS/BAS scales immediately before EEG collection. The 20-question scale is comprised of four scales: BIS, which has seven items that measure reactions to the expectation of punishment; BAS drive, which contains four items that pertain "to the persistent pursuit of desired goals"; BAS reward responsiveness, which contains five items that "focus on positive responses to the occurrence or anticipation of reward"; and BAS fun seeking, which has four items "reflecting both a desire for new rewards and a willingness to approach a potentially rewarding event on the spur of the moment" (p. 322). The methodology (data collection and reduction) and data analysis was the same as in Study 1.

5. Results

As in Study 1, a main effect of season was found, so that relative right lateral frontal cortical activity was greatest in the fall, $\beta = -.42$, $R^2 = .19$, $t(61) = 3.83$, $p < .001$. Additionally, TOD and TOY interactively predicted lateral frontal asymmetry, $\beta = .23$, $R^2 = .06$, $t(61) = 2.03$, $p < .05$ (see Fig. 2). Relative right lateral frontal cortical activity tended to be greatest during fall mornings compared to fall afternoons, $t(61) = 1.26$, $p = .10$ (one-tailed). Lateral frontal asymmetry did not vary by TOD in the spring, $t(61) = -.28$, $p > .39$. No main effect of TOD was found, $\beta = .14$, $R^2 = .03$, $t(61) = 1.29$, $p > .19$. Mid-frontal asymmetry was not affected by TOD, TOY or their interaction, βs $< .12$, $R^2 < .01$, $t(61) < .93$, $ps > .35$, and no significant effects were found for the parietal region, βs $< .09$, $R^2 < .01$, $t(61) < .74$, $ps > .46$.

As in Study 1, we conducted a planned comparison in which fall mornings were coded as 3 and the other three conditions were coded as -1. Relative right frontal cortical activity was significantly greater during fall mornings compared to fall afternoons, spring mornings, and spring afternoons, $\beta = -.35$, $R^2 = .13$, $t(63) = 3.0$, $p < .01$.

In order to test whether BIS/BAS sensitivity varied by TOD or season, we conducted regressions in which TOD, TOY, and their interaction were entered as predictors of each of the BIS/BAS scales. No significant effects were found, $ps > .20$. We then independently entered each centered scale/subscale as a control variable when predicting lateral frontal asymmetry. None of the scales were significant predictors, $ps > .14$. In addition, the main effect of TOY and the TOD $\times$ TOY interaction remained significant when controlling for BIS/BAS in separate regressions, $ps < .05$.

[4] Breakdown of participants run by month: February, 7; March, 8; April, 13; October, 17; November, 21.

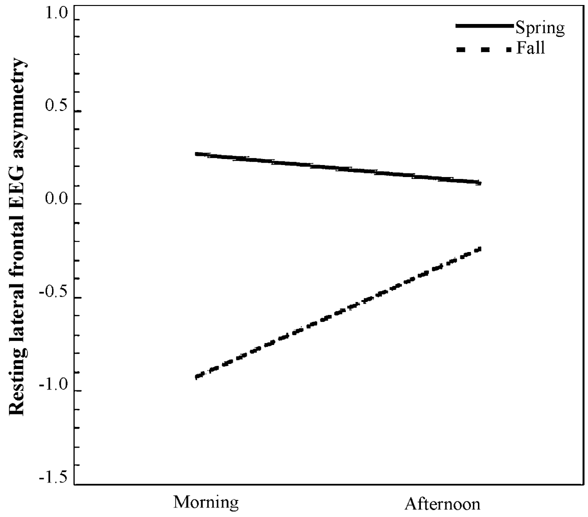

Fig. 2. Study 2: Time of Day × Time of Year interaction predicts resting lateral frontal asymmetry (plotted using guidelines by Aiken and West (1991) and thus values are estimates). Lower asymmetry scores indicate greater relative right than left cortical activity.

6. Discussion

Study 2 replicated Study 1 in that lateral frontal asymmetry varied by season, so that relative right frontal cortical activity was greatest in the fall. Furthermore, this variation was moderated by TOD. While the slope of the regression line in fall was marginal, it fits the pattern of relative right frontal cortical activity being greatest in fall mornings.

Unlike Study 1, there was no effect of TOD or TOY on relative right mid-frontal cortical activity at rest. This null effect is consistent with the asymmetrical frontal EEG literature, in which "relationships with frontal EEG asymmetry appear. . .at different regions at different times" (Allen et al., 2004, p. 26). Future research using high-density electrode arrays (and perhaps source localization) should explore why asymmetrical frontal effects behave in this manner.

Given that situational variables explain about half of the variance in resting, frontal EEG asymmetry, Study 2 demonstrated that seasonal changes account for nearly 40% of this variability. While frontal asymmetry did not vary significantly by TOD, the interaction of TOD and TOY explains approximately 12% of this state variance.

Study 2 also showed that trait BIS/BAS sensitivity did not vary by TOD, TOY, or TOD × TOY. Furthermore, the main effect of TOY and TOD × TOY interaction remained significant predictors of frontal asymmetry when controlling for individual differences in BIS/BAS sensitivity.

7. General discussion

Resting frontal EEG asymmetry varied as a function of season and TOD. Two studies demonstrated that greater relative right lateral frontal activity was highest in the fall, particularly in the morning. These relationships are consistent with circadian and seasonal variations of basal cortisol and mood. No relationships were found between parietal asymmetry and TOD or TOY, consistent with most past research that has not found relationships between parietal asymmetry and basal cortisol or mood.

It is possible that state mood could explain the present results. Indeed, such would be consistent with past research suggesting that mood changes as a function of season and may be related to basal cortisol. For example, it may be that we simply ran more depressed subjects in fall mornings, which would explain why we found increased relative right frontal cortical activity at this time. This explanation, however, could not be examined in the present studies because of the lack of mood measures. However, some past studies failed to find significant relationships between self-reported mood and resting frontal asymmetry (e.g., for review, see Hagemann, 2004), suggesting that self-reported mood may not be sufficiently sensitive to produce relationships with asymmetrical frontal cortical activity at rest. Furthermore, research has shown that acute administration of cortisol increases relative right frontal cortical activity, but does not affect self-reported mood (Tops et al., 2005). Additionally, research has shown that depressed individuals stay up later and get up later (Chelminski et al., 1999; Drennan et al., 1991). Consequently, depressed individuals may not have been as likely to attend, and thus it is unlikely that their presence in fall mornings explain our results.

Individual differences in personality (e.g. IAS-R) are among the many "3rd variables" that may affect the relationships between TOD, season, and frontal asymmetry. However, the present studies demonstrated that (a) TOD and TOY do not interactively predict personality or BIS/BAS sensitivity and (b) the TOD × TOY interaction still predicted lateral frontal asymmetry when controlling for these individual differences. Thus, we suspect that these major personality characteristics did not affect self-selection into the sessions and thus do not explain our results.

However, other 3rd variables may explain our results and should be examined in future research (e.g., time since eaten, body temperature; Geisler and Polich, 1990). Future research should also consider latitudinal location as a factor. Additionally, state mood could be examined as a possible factor, although past research has not found it to relate to resting frontal EEG asymmetry (Hagemann, 2004).

The observed variations in resting frontal EEG asymmetry have important implications for future research and may assist in explaining why some past research failed to find predicted relationships between resting frontal asymmetry and emotive dispositions. Recent research has demonstrated that situational factors should be considered when examining an individual's resting EEG asymmetry (Hagemann et al., 2002, 2005). In fact, "findings consistently suggest that as much as 40% or 50% of the variance of anterior resting EEG asymmetry measures from single occasions may be due to unwanted state-like fluctuations" (Hagemann et al., 2005, pp. 749–750). The present results suggest that TOD and TOY are two situational factors that may relate to an individual's resting EEG asymmetry and should be considered when using frontal asymmetry as an individual difference measure. At the very least, to assist in the interpretation of the results, future research on resting EEG asymmetry should report when participants' data were collected and ensure that different groups of individuals (depressed vs. non-depressed) are not run at different times of day or during different seasons.

In addition to these methodological considerations, the present studies further underscore the importance of examining situational influences on resting, baseline frontal asymmetry. The results also suggest that variables related to relative right frontal cortical activity might also vary as a function of TOD and season. For example, our results suggest that individuals run in fall mornings may be more withdrawal-oriented. Consequently, these findings suggest the promise of examining whether there are seasonal or circadian variations in a variety of characteristics, including aggressiveness (Peterson et al., 2008), anxiety (Davidson et al., 2000), depression (Henriques and Davidson, 1991), or the likelihood to reduce cognitive dissonance (Harmon-Jones et al., 2008).

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