Published in final edited form as:

Pers Individ Dif. 2017 January ; 104: 69–74. doi:10.1016/j.paid.2016.07.036.

Constraint is associated with earlier circadian phase and morningness: Confirmation of relationships between personality and circadian phase using a constant routine protocol

B. Bullock^{a,*}, G. Murray^a, J.L. Anderson^{b,d}, T. Cooper-O'Neill^c, J.J. Gooley^{c,d,e}, S.W. Cain^{c,d,e}, and S.W. Lockley^{c,d,e}

^a Department of Psychological Sciences, Swinburne University of Technology, Melbourne, Australia

^b Department of Psychiatry, Brigham and Women's Hospital and Harvard Medical School, Boston, USA

^c Division of Sleep and Circadian Disorders, Brigham and Women's Hospital, Boston, USA

^d Division of Sleep Medicine, Harvard Medical School, Boston, USA

^e Monash Institute of Cognitive and Clinical Neurosciences, School of Psychological Sciences, Monash University, Clayton, Australia

Abstract

Associations among personality, diurnal preference, and circadian phase were investigated using a constant routine laboratory protocol. One hundred and sixty-eight healthy participants aged 18-30 years (Women $n = 68$) completed either a 30- or 50-hour constant routine under dim-light conditions (<3 lux), during which circadian phase was measured from core body temperature and melatonin. Prior to laboratory admission, self-report measures of personality and diurnal preference were also obtained. The personality trait of Constraint correlated positively with morning diurnal preference and earlier circadian phase, with circadian phase partially mediating the relationship between Constraint and diurnal preference. No other personality variables correlated with circadian phase. Sex was an important covariate in several of the relationships investigated due to lower levels of Constraint and later CBT phase amongst men and was thus controlled for in all relevant analyses. Findings from this highly controlled study are consistent with previous field research in suggesting that earlier circadian phase is associated with the personality trait of Constraint.

Keywords

Constraint; Diurnal Preference; Chronotype; Circadian; Constant Routine; DLMO; Melatonin; Core Body Temperature; Phase

*Corresponding author: bbullock@swin.edu.au.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

1. Introduction

At a fundamental level people differ in their typical behaviours, thoughts, feelings, and motivations. These personality traits are relatively stable across both time and situation, and develop through interacting biological, social, and developmental processes (Briley & Tucker-Drob, 2014). It is also well established that people differ in self-reported diurnal preference (preferred sleep/wake times and periods of peak activity; Horne & Ostberg, 1976;) and several characteristics of the internal circadian clock (e.g., circadian phase; Duffy, Dijk, Hall, & Czeisler, 1999). The relationship between personality traits and self-reported diurnal preference is the subject of a growing body of research (e.g., Adan et al., 2012; Randler, Goma-I-Freixanet, Muro, Knauber, & Adan, 2015); however, few studies have investigated relationships between personality traits and objective measures of the circadian clock. Studies employing objective measures of circadian variables are important as they will serve to clarify the nature of relationships between personality and reports of diurnal preference found using self-report methods.

Investigations of relationships between diurnal preference and structural models of personality have consistently demonstrated positive associations. The trait of Conscientiousness in particular has been shown to have a strong relationship with diurnal preference, with those scoring higher on Conscientiousness tending towards a Morningness preference (Adan et al., 2012; Randler, Baumann, & Horzum, 2014; Tonetti, Fabbri, & Natale, 2009). Similarly, a metatrait of Stability (consisting of high Conscientiousness, high Agreeableness, and low Neuroticism) was found to be a strong predictor of Morningness (DeYoung, Hasher, Djikic, Criger, & Peterson, 2007). Other traits closely associated with Conscientiousness – for example, Persistence (Adan, Lachica, Caci, & Natale, 2010) and Behavioural control (Ottoni, Antoniolli, & Lara, 2012) – have also demonstrated moderate to strong relationships with Morningness. These findings have been used to argue that higher levels of Conscientiousness are associated with earlier circadian phase (e.g., Hogben, Ellis, Archer, & Von Schantz, 2007).

Two potentially erroneous assumptions underpin the proposal that Conscientiousness is associated with circadian phase. First, when two related constructs are measured via self-report in a cross-sectional design study, common method variance can artificially inflate the size of the correlation (Podsakoff, MacKenzie, & Podsakoff, 2012). Second, subjective diurnal preference reports are not solely contingent upon circadian phase but also the related and equally important chronobiological variables of internal *phase angle* (the timing of sleep relative to circadian phase; Dijk & Lockley, 2002) and homeostatic sleep regulation (Mongrain, Lavoie, Selmaoui, Paquet, & Dumont, 2004). To overcome these limitations in existing self-report studies, investigations using an objective marker of circadian phase are required.

Two commonly used objective, biological indicators of circadian function are melatonin release and core body temperature rhythm. Measured under dim light conditions, plasma or salivary melatonin levels in the bloodstream are commonly used to estimate the phase of the circadian clock (Benloucif et al., 2008). A Constant Routine (CR) laboratory protocol

(Minors & Waterhouse, 1984) used in conjunction with melatonin assessment is a precise method for measuring circadian phase (Duffy & Dijk, 2002). The CR laboratory protocol strictly controls participant behaviour (continued wakefulness, regular isocaloric food intake, constant semi-recumbent posture) and environmental conditions (constant dim light, ambient temperature) that otherwise create masking factors confounding output measures of the circadian clock. The onset of melatonin secretion (Dim Light Melatonin Onset, or DLMO; Lewy & Sack, 1989) is a commonly used marker of circadian phase under these conditions. Core body temperature (CBT) is also used as a measure of circadian output, with the time at which the circadian temperature rhythm reaches its minimum used as the phase marker (Brown & Czeisler, 1992). The CR protocol provides a more reliable and valid estimate of circadian phase than do similar measurements of melatonin or CBT taken in ambulatory subjects who are subject to day/night variability of light/dark cycles, meals, and other periodic environmental stimuli (e.g., Klerman, Lee, Czeisler, & Kronauer, 1999).

Evidence for a link between personality and circadian phase has been suggestive, but not definitive. In a field study of healthy young adults, Baehr, Revelle, and Eastman (2000) found that earlier CBT minimum in ambulatory participants was associated with higher levels of Constraint. Constraint is a personality trait that ranges from control at one end to impulsivity at the other (Harkness, McNulty, & Ben-Porath, 1995), so this finding is seemingly consistent with studies reporting associations between Conscientiousness and Morningness using self-report methods (Hogben et al., 2007; Tonetti et al., 2009). Like the self-report methods however, monitoring of ambulatory CBT to derive a circadian phase marker is problematic - masking effects of movement and postural change on the underlying circadian rhythm in CBT make the phase assessment highly unreliable (Klerman, Lee, Czeisler, & Kronauer, 1999).

The aim of the current study therefore, was to clarify key findings from the research linking personality and measures of circadian phase using a tightly controlled CR laboratory protocol. Based on previous research, two specific hypotheses were proposed. First, it was expected that, amongst personality trait predictors, Constraint would show the strongest association with circadian phase, and that it would be associated with earlier CBT and DLMO phase position. Second, it was expected that Constraint would be positively associated with self-reported Morningness. Rigorous laboratory measures of circadian parameters also provided the opportunity to conduct two novel exploratory analyses. First, possible mediating effects of circadian phase on the relationship between Constraint and diurnal preference were explored in order to clarify the nature of the association between these self-report variables. Second, an investigation of relationships between Constraint and two measures of phase angle (DLMO phase relative to sleep time and CBT phase relative to wake time) was conducted to clearly differentiate these circadian variables from their associated measures of circadian phase. A series of preliminary analyses also tested the possible moderating effects of sex on the relationships of interest. Sex differences in the circadian variables of interest have previously been demonstrated by Cain et al. (2010) and may be an important moderator of relationships between personality and the circadian variables. Sex differences in diurnal preference are also of interest for the same reason, having been demonstrated in previous research by Adan and Natale (2002).

2. Method

2.1 Participants

As part of a larger study, and recruited throughout the period 2001-2010, 168 participants (Men $n = 100$; Women $n = 68$) aged 18-30 years ($M = 22.65$) took part in a CR protocol in the Intensive Physiology Monitoring Unit at Brigham and Women's Hospital (Boston, MA). Prior to entering the study, participants underwent comprehensive physical and psychological screening and were found to be healthy and within normal limits on all tests. For three weeks prior to admission, participants were required to maintain a regular 8-hour sleep-wake schedule (compliance confirmed by time- and date-stamped voicemails, as well as actigraphic monitoring for at least 7 days prior to admission) and refrain from using prescription, non-prescription, and illicit drugs (compliance confirmed by blood and urine toxicology). The studies were approved by the Human Research Committee of the Partners HealthCare System and were conducted in accordance with the Declaration of Helsinki. All participants gave written informed consent prior to the study.

2.2 Materials and Equipment

The MMPI-2 was used to screen for psychopathology, and also to derive a five-factor measure of personality, the PSY-5 (Harkness et al., 1995). The PSY-5 is a five-factor measure of personality that is broadly comparable to commonly used normal personality measures. It consists of scales measuring Aggressiveness, Psychoticism, Constraint, Positive Emotionality, and Negative Emotionality. Psychometric properties of the PSY-5 in both clinical and healthy populations are adequate (Harkness et al., 1995).

Diurnal preference was assessed using the 19-item Morningness-Eveningness Questionnaire (MEQ; Horne & Ostberg 1976). Scores on the MEQ range from 16 to 86, with higher scores indicating greater Morningness. Good internal consistency has been reported for the MEQ and validation with external criteria has also been demonstrated (see, Di Milia, Adan, Natale, & Randler, 2013).

Physiological indices of circadian phase were derived from both melatonin (hourly plasma and, occasionally, salivary) and core body temperature. Detailed descriptions of sample collection and assay procedures for melatonin in this sample are available elsewhere (St Hilaire et al., 2012). In the current study, the circadian phase marker for melatonin was DLMO, calculated from 25% of the fitted three-harmonic peak-to-trough amplitude of the melatonin rhythm (St Hilaire et al., 2012). CBT was measured continuously using a rectal thermistor. CBT minimum was derived from fitted 2-harmonic regression models (Brown & Czeisler, 1992). While phase indicates a point within an endogenous circadian rhythm, in this instance reported in clock time, how two rhythms relate to each other is described as the *phase angle* (classically defined in degrees where one circadian cycle = 360°). We examined the phase angle between circadian phase and the sleep/wake cycle given the fundamental role that the timing of sleep relative to circadian phase plays in the quality of sleep and wake behaviour (e.g., Czeisler, Weitzman, Moore-Ede, Zimmerman, & Knauer, 1980; Lockley et al., 2008). Two measures of phase angle were therefore measured alongside circadian phase: DLMO phase angle was measured as the distance (in time) between DLMO and habitual

sleep time. CBT phase angle was measured as the distance (in time) between CBT minimum and habitual wake time.

2.3 Procedure

The CR protocol and data collection procedures have been described in detail elsewhere (e.g., St Hilaire et al., 2012). Following a three-day inpatient baseline under controlled light-dark conditions, participants completed the CR where they were required to lie awake in a semi-recumbent position under dim-light conditions (<3 lux) for between 30 and 50 hours in an environment free of windows, clocks, watches, TV, radio, internet, telephones, and newspapers. Small, isocaloric meals and equal fluids were provided hourly (2000 or 2500 ml of fluid per 24-hours). Ambient light was provided by 4100K fluorescent lamps (Philips Lighting, The Netherlands). During the CR protocol, the mean illuminance at eye level was 0.52 ± 0.10 lux (0.001 W/m², at 137 cm from the floor in the vertical plane).

3. Results

Table 1 presents descriptive statistics for all variables split by sex. Men and women differed significantly on four variables, with men scoring higher on Aggressiveness $t(164) = 2.10$, $p < .05$, $d = 0.34$ and (Dis)constraint $t(164) = 4.52$, $p < .001$, $d = 0.72$, and lower on NE $t(164) = 3.06$, $p < .01$, $d = 0.49$. Men also exhibited a later CBT Phase than women ($t(152) = 3.15$, $p < .01$, $d = 0.53$). No significant sex differences were observed in MEQ scores.

3.1 Relationships between diurnal preference and circadian measures

Preliminary investigation of correlations between diurnal preference and both CBT and DLMO measures of phase found that Morningness was associated with earlier circadian phase (Table 2). This relationship was also obtained when analyses were conducted separately for men and women (Figure 1a and Figure 1b). Both measures of phase correlated negatively and strongly with their respective measures of phase angle. The negative relationships indicate that smaller phase angles between circadian phase and habitual sleep/wake times were associated with a later circadian phase. Diurnal preference correlated positively with CBT phase angle (Table 2; see also Figure 2a and Figure 2b), suggesting that self-reported Morningness is associated with a larger phase angle. In the current data, this relationship was statistically significant for men only. The relationship between diurnal preference and DLMO phase angle was not significant overall, nor was it significant for either sex.

3.2 Relationships among personality, circadian measures and diurnal preference

As shown in Table 2, Constraint exhibited small-moderate negative correlations with both measures of phase, and small positive correlations with both CBT phase angle and diurnal preference. Negligible associations were found between the circadian variables and the remaining personality traits (NE, PE, Psychoticism, and Aggressiveness). Similarly, there were no significant correlations between diurnal preference and these personality variables.

Hierarchical regressions were used to evaluate the strength of the relationship between Constraint and circadian phase while controlling for the influence of Sex. Predicting DLMO

phase, the overall model approached statistical significance, $F(2,135) = 2.96, p = .05$, explaining 4.2% variance. Constraint was a significant predictor of DLMO phase after controlling for Sex, $\beta = -.18, p < .05, pr^2 = .03$. The model predicting CBT phase using Constraint and Sex was significant, $F(2,149) = 9.60, p < .001$, explaining 11.4% variance. Sex was a significant predictor of CBT phase at Step 1, confirming the results of the earlier t-test, and Constraint was a significant predictor of CBT phase at Step 2, $\beta = -.24, p < .01, pr^2 = .05$. The model predicting CBT phase angle using Constraint and Sex was not significant, $F(2,148) = 2.50, p = .09$.

Hierarchical regression was used to investigate the relationship between Constraint and diurnal preference, again controlling for Sex at Step 1. The overall model was significant, $F(2,159) = 4.17, p < .05$, explaining 5% variance. Constraint was a significant predictor of diurnal preference over and above the influence of Sex, $\beta = .22, p < .01, pr^2 = .04$.

Exploratory investigations of CBT phase as a potential mediator of the relationship between Constraint and diurnal preference (controlling for the effects of Sex) found a significant overall mediation model, $r = .09$, 95% CI [.03, .15]. The relationship between Constraint and diurnal preference was partially mediated by CBT phase, $r = .03$, 95% CI [.01, .06]. The same analysis run with DLMO phase as the putative mediator again found a significant overall mediation model $r = .08$, 95% CI [.01, .14], however in this analysis no statistically significant mediating effect of DLMO phase was found, $r = .02$, 95% CI [.00, .05].

4. Discussion

Both hypotheses were supported by the data: Higher levels of Constraint were associated with earlier circadian phase and greater Morningness. Exploratory investigations produced two novel findings: Partial mediation by CBT phase of the relationship between Constraint and diurnal preference was observed, and Constraint was positively correlated with a measure of CBT phase angle, but not DLMO phase angle.

Constraint was the sole personality variable to correlate significantly with circadian phase. Hierarchical regressions confirmed that this finding was robust to the effects of participants' sex on phase. Explained variance in the model was substantially greater in the regression model for CBT phase than DLMO phase, but this was mainly due to the significant contribution of sex to the prediction of CBT phase. Consistent with the laboratory study of Cain et al. (2010) and the field study of Baehr et al. (2000), men in the sample had a later circadian phase than women. The negative relationship found between Constraint and circadian phase was also consistent with the field study of Baehr et al. (2000).

Higher levels of Constraint were associated with a morning-oriented diurnal preference. Again, this finding remained after controlling for covariance attributed to participants' sex in a hierarchical regression. The finding is consistent with that of Baehr et al. (2000) who reported a correlation between the personality trait of Constraint and diurnal preference of similar magnitude to the current study. This finding is also consistent with previous studies reporting positive correlations between Morningness and Conscientiousness (Hogben et al., 2007; Tonetti et al., 2009; see also Adan et al., 2012) and Conscientiousness-related traits

(Adan et al., 2010; DeYoung et al., 2007; Ottoni et al. 2012). Contrary to previous research (e.g., Adan & Natale, 2002), we did not find differences in Morningness between men and women.

The mediating effects of CBT phase and (to a lesser extent) DLMO phase on the relationship between Constraint and diurnal preference suggest that some part of this association can be attributed to circadian phase *per se*. Self-reported diurnal preference reflects a complex combination of circadian and non-circadian input, however; the latter including sleep/wake mechanisms, developmental processes, and social behaviour. As only 16% of variance in MEQ score was explained by circadian phase, we would caution against sole reliance on subjective assessments of diurnal preference to draw conclusions regarding circadian phase.

Exploratory investigations of links between Constraint and phase angle of the endogenous circadian pacemaker with habitual wake time (CBT) and sleep time (DLMO) showed that personality correlates of circadian phase did not generalise to these measures of phase angle. Future studies in this area may therefore need to consider measures of phase separately from measures of phase angle that incorporate sleep/wake timing information. We are unable to provide firm conclusions on why Constraint did not correlate with phase angle in the same way that it did with phase. It is possible that the protocol enforcing an 8-hour sleep schedule on participants interfered with the natural relationship between their endogenous circadian rhythm and sleep/wake cycle. Such a hypothesis would need to be tested in a different study.

Positive relationships in the current study between higher MEQ scores and phase angle of the endogenous circadian pacemaker with habitual wake time (CBT) and sleep time (DLMO) confirm previous findings (e.g., Duffy et al., 1999). That higher MEQ scores were associated with a larger phase angle suggests that higher levels of Morningness are associated with wake times at relatively later circadian phase positions than at lower levels of Morningness, even though higher levels are associated with an earlier waking clock time. Duffy, Rimmer, and Czeisler (2001) suggest that shorter circadian periods explain these differences between Morning- and Evening-types in phase angle relationships, although other potential mechanistic explanations (e.g., variations in so-called “clock genes”; Lazar et al., 2012) cannot be wholly excluded.

4.1 Limitations

Along with most published studies based on sleep laboratory protocols, the sample used here were, due to rigorous screening procedures, unusually robust physically and psychologically. In comparison to the normative sample of Harkness et al. (1995), the current sample had significantly lower mean scores on PSY-5 domains (all $p < .001$). The NEO PI-R (Costa & McCrae, 1992) may have more power to identify personality variables in a sample such as the one employed here. While Constraint would appear to be closely related to the common Five Factor trait of Conscientiousness, the relationship between Constraint and Conscientiousness is more complicated than this simple characterisation (Harkness et al., 1995). Given the prominent role of Constraint in the circadian-personality relationships reported here, future studies should pay careful attention to the selection of personality measures. Investigations that employ models of personality that are biological in origin (e.g.,

Reinforcement Sensitivity Theory; Gray, 1991) are also recommended given the strong biological basis of circadian and related variables.

4.2 Conclusions and Future Directions

The current study supports previous findings of a small, significant relationship between Constraint and circadian phase. The study extends previous findings by incorporating standardised laboratory measures of circadian phase, providing a clearer scientific picture of the association between personality traits and circadian phase. Specifically, Constraint was associated with two distinct laboratory measures of earlier circadian phase and a morning-oriented diurnal preference. Methodologically, the findings demonstrate the importance of differentiating measures of phase and phase angle in future research into the association between personality traits and circadian function.

By bringing together individual difference psychology and chronobiological research, the present project raises important hypotheses for future study. For example, it will be important to investigate causal relationships between personality and circadian phase: Does the morning preference associated with the self-control characteristics of Constraint tend to advance circadian rhythms through early light exposure, or do advanced circadian rhythms encourage the morning preference that is linked to Constraint? Moreover, both Constraint and Morningness are associated with positive well-being outcomes. Future studies could usefully quantify the extent to which these benefits are mediated through rewards associated with Constraint (social and economic status benefits of conventionalism, for example), versus the direct benefits of early phase and stable sleep-wake cycles for emotion regulation. These are intrinsically multi-level questions about human behaviour in the environment. It is likely that genetic components of the endogenous circadian clock interact with personality traits and social behaviour to influence diurnal preference. It is also possible, however, that, given the circadian system operates on an open feedback loop (e.g., Bechtel, 2010; Morin, 2013), personality traits and social behaviour influence exposure to light-dark patterns and other cues that modulate the timing of circadian rhythms. Determining the precise nature of personality/circadian relationships is important, given Western societies' increasingly 24-hour social cycle, and the consequences of this cycle for individual and societal physical and mental well-being.

Acknowledgements

This work was supported by grants from the National Institute of Mental Health (R01 MH45130; Czeisler/Lockley), National Center for Complementary and Alternative Medicine (R01 AT002129; Czeisler/Lockley), National Institute of Neurological Disorders and Stroke (R01 NS36590; Brainard), and was performed in the Brigham and Women's Hospital General Clinical Research supported by M01 RR02635 and the Harvard Clinical and Translational Science Center (1 UL1 RR025758), from the National Center for Research Resources. Dr Gooley was supported by a National Heart, Lung and Blood Institute fellowship in the program of training in Sleep, Circadian and Respiratory Neurobiology at Brigham and Women's Hospital (T32 HL079010). Dr. Lockley was supported in part by the National Space Biomedical Research Institute through NASA NCC 9-58.

References

- Adan A, Archer SN, Hidalgo MP, Di Milia L, Natale V, Randler C. Circadian typology: A comprehensive review. *Chronobiology International*. 2012; 29(9):1153–1175. doi: 10.3109/07420528.2012.719971. [PubMed: 23004349]

- Adan A, Lachica J, Caci H, Natale V. Circadian typology and temperament and character personality dimensions. *Chronobiology International*. 2010; 27(1):181–193. doi: 10.3109/07420520903398559. [PubMed: 20205565]
- Adan A, Natale V. Gender differences in morningness-eveningness preference. *Chronobiology International*. 2002; 19(4):709–720. doi:10.1081/cbi-120005390. [PubMed: 12182498]
- Baehr EK, Revelle W, Eastman CI. Individual differences in the phase and amplitude of the human circadian temperature rhythm: With an emphasis on morningness-eveningness. *Journal of Sleep Research*. 2000; 9(2):117–127. doi: 10.1046/j.1365-2869.2000.00196.x. [PubMed: 10849238]
- Bechtel W. The downs and ups of mechanistic research: circadian rhythm research as an exemplar. *Erkenntnis*. 2010; 73(3):313–328.
- Benloucif S, Burgess HJ, Klerman EB, Lewy AJ, Middleton B, Murphy PJ, Revell VL. Measuring melatonin in humans. *Journal of Clinical Sleep Medicine*. 2008; 4(1):66–69. [PubMed: 18350967]
- Briley DA, Tucker-Drob EM. Genetic and environmental continuity in personality development: A meta-analysis. *Psychological Bulletin*. 2014; 140(5):1303–1331. doi: 10.1037/a0037091. [PubMed: 24956122]
- Brown EN, Czeisler CA. The statistical analysis of circadian phase and amplitude in constant-routine core-temperature data. *Journal of Biological Rhythms*. 1992; 7(3):177–202. [PubMed: 1421473]
- Cain SW, Dennison CF, Zeitzer JM, Guzik AM, Khalsa SBS, Santhi N, Duffy JF. Sex differences in phase angle of entrainment and melatonin amplitude in humans. *Journal of Biological Rhythms*. 2010; 25(4):288–296. doi:10.1177/0748730410374943. [PubMed: 20679498]
- Costa, PT., McCrae, RR. Revised NEO Personality Inventory and NEO Five-Factor Inventory professional manual. Psychological Assessment Resources; Odessa, FLA: 1992.
- Czeisler CA, Weitzman ED, Moore-Ede MC, Zimmerman JC, Knauer RS. Human sleep: Its duration and organization depend on its circadian phase. *Science*. 1980; 210(4475):1264–1267. [PubMed: 7434029]
- DeYoung CG, Hasher L, Djikic M, Criger B, Peterson JB. Morning people are stable people: Circadian rhythm and the higher-order factors of the Big Five. *Personality and Individual Differences*. 2007; 43(2):267–276. doi: 10.1016/j.paid.2006.11.030.
- Dijk DJ, Lockley SW. Invited review: Integration of human sleep-wake regulation and circadian rhythmicity. *Journal of Applied Physiology*. 2002; 92(2):852–862. [PubMed: 11796701]
- Di Milia L, Adan A, Natale V, Randler C. Reviewing the psychometric properties of contemporary circadian typology measures. *Chronobiology International*. 2013; 30(10):1261–1271. doi: 10.3109/07420528.2013.817415. [PubMed: 24001393]
- Duffy JF, Dijk DJ. Getting through to circadian oscillators: Why use constant routines? *Journal of Biological Rhythms*. 2002; 17(1):4–13. doi:10.1177/074873002129002294. [PubMed: 11837947]
- Duffy JF, Dijk DJ, Hall EF, Czeisler CA. Relationship of endogenous circadian melatonin and temperature rhythms to self-reported preference for morning or evening activity in young and older people. *Journal of Investigative Medicine*. 1999; 47(3):141–150. [PubMed: 10198570]
- Duffy JF, Rimmer DW, Czeisler CA. Association of intrinsic circadian period with morningness-eveningness, usual wake time, and circadian phase. *Behavioral Neuroscience*. 2001; 115(4):895–899. doi:10.1037/0735-7044.115.4.895. [PubMed: 11508728]
- Duffy JF, Wright KP Jr. Entrainment of the human circadian system by light. *Journal of Biological Rhythms*. 2005; 20(4):326–338. doi: 10.1177/0748730405277983. [PubMed: 16077152]
- Gray, JA. The neuropsychology of temperament.. In: Strelau, J., Angleitner, A., editors. *Explorations in Temperament: International Perspectives on Theory and Measurement*. Springer; New York, NY: 1991. p. 105-128.
- Harkness AR, McNulty JL, Ben-Porath YS. The Personality Psychopathology Five (PSY-5): Constructs and MMPI-2 scales. *Psychological Assessment*. 1995; 7(1):104–114. doi: 10.1037/1040-3590.7.1.104.
- Hogben AL, Ellis J, Archer SN, Von Schantz M. Conscientiousness is a predictor of diurnal preference. *Chronobiology International*. 2007; 24(6):1249–1254. doi: 10.1080/07420520701791596. [PubMed: 18075811]

- Horne JA, Ostberg O. A self-assessment questionnaire to determine morningness eveningness in human circadian rhythms. *International Journal of Chronobiology*. 1976; 4:97–110. [PubMed: 1027738]
- Klerman EB, Lee Y, Czeisler CA, Kronauer RE. Linear demasking techniques are unreliable for estimating the circadian phase of ambulatory temperature data. *Journal of Biological Rhythms*. 1999; 14(4):260–274. [PubMed: 10447306]
- Lazar AS, Slak A, Lo J, Santhi N, von Schantz M, Archer SN, Dijk DJ. Sleep, diurnal preference, health, and psychological well-being: A prospective single-allelic-variation study. *Chronobiology International*. 2012; 29(2):131–146. doi:10.3109/07420528.2011.641193. [PubMed: 22324552]
- Lewy AJ, Sack RL. The dim light melatonin onset as a marker for circadian phase position. *Chronobiology International*. 1989; 6(1):93–102. [PubMed: 2706705]
- Minors DS, Waterhouse JM. The use of constant routines in unmasking the endogenous component of human circadian rhythms. *Chronobiology International*. 1984; 1(3):205–216. [PubMed: 6600027]
- Mongrain V, Lavoie S, Selmaoui B, Paquet J, Dumont M. Phase relationships between sleep-wake cycle and underlying circadian rhythms in morningness-eveningness. *Journal of Biological Rhythms*. 2004; 19(3):248–257. doi: 10.1177/0748730404264365. [PubMed: 15155011]
- Morin LP. Neuroanatomy of the extended circadian rhythm system. *Experimental Neurology*. 2013; 243:4–20. doi: <http://dx.doi.org/10.1016/j.expneurol.2012.06.026>. [PubMed: 22766204]
- Ottoni GL, Antonioli E, Lara DR. Circadian preference is associated with emotional and affective temperaments. *Chronobiology International*. 2012; 29(6):786–793. doi: 10.3109/07420528.2012.679329. [PubMed: 22734579]
- Podsakoff PM, MacKenzie SB, Podsakoff NP. Sources of method bias in social science research and recommendations on how to control it. *Annual Review of Psychology*. 2012; 63:539–569. doi: 10.1146/annurev-psych-120710-100452.
- Randler C, Baumann VP, Horzum MB. Morningness-eveningness, Big Five and the BIS/BAS inventory. *Personality and Individual Differences*. 2014; 66:64–67. doi:10.1016/j.paid.2014.03.010.
- Randler C, Gomà-I-Freixanet M, Muro A, Knauber C, Adan A. Do different circadian typology measures modulate their relationship with personality? A test using the Alternative Five Factor Model. *Chronobiology International*. 2015; 32(2):281–288. doi: 10.3109/07420528.2014.968282. [PubMed: 25290037]
- St Hilaire MA, Gooley JJ, Khalsa SBS, Kronauer RE, Czeisler CA, Lockley SW. Human phase response curve to a 1 h pulse of bright white light. *Journal of Physiology*. 2012; 590(13):3035–3045. doi: 10.1113/jphysiol.2012.227892. [PubMed: 22547633]
- Tonetti L, Fabbri M, Natale V. Relationship between circadian typology and big five personality domains. *Chronobiology International*. 2009; 26(2):337–347. doi: 10.1080/07420520902750995. [PubMed: 19212845]

Highlights

- Constraint was associated with Morningness and earlier circadian phase
- Morningness was associated with earlier circadian phase and a larger phase angle
- Circadian phase partially mediated the relationship between Constraint and Morningness
- Sex was an important covariate due to lower levels of Constraint and later circadian phase amongst men

Figure 1.

(a) CBT phase measured in 24-hour clock time plotted against MEQ score, data presented separately for women ($n = 67$; $R^2 = .13$) and men ($n = 99$; $R^2 = .19$). (b) DLMO phase measured in 24-hour clock time plotted against MEQ score, data presented separately for women ($n = 67$; $R^2 = .10$) and men ($n = 99$; $R^2 = .20$). In both graphs, higher MEQ scores indicate a preference towards Morningness.

Figure 2.

(a) CBT phase angle measured in hours plotted against MEQ score, data presented separately for women ($n = 67$; $R^2 = .03$) and men ($n = 99$; $R^2 = .08$). (b) DLMO phase angle measured in hours plotted against MEQ score, data presented separately for women ($n = 67$; $R^2 = .00$) and men ($n = 99$; $R^2 = .02$). In both graphs, higher MEQ scores indicate a preference towards Morningness.

Table 1

Descriptive Statistics for Self-report Scales and Circadian Variables Split by Sex

	Men (<i>n</i> = 99)			Women (<i>n</i> = 67)		
	<i>M</i>	<i>SD</i>	<i>Range</i>	<i>M</i>	<i>SD</i>	<i>Range</i>
PSY-5						
NE	4.26	3.33	0-16	5.96	3.66	0-16
PE	8.54	3.49	2-17	8.39	3.35	2-17
Agg	7.13	2.34	1-12	6.40	1.96	2-11
$\uparrow$ Con	14.27	3.57	5-24	11.82	3.20	5-19
Psy	2.71	2.04	0-10	2.84	2.23	0-10
MEQ	50.45	8.48	30-68	51.85	8.14	32-72
Phase						
DLMO	22:33	1:17	19:43-2:25	22:15	1:14	19:11-0:57
CBTmin	5:15	1:33	1:16-9:48	4:27	1:29	0:47-7:52
Phase angle						
DLMO	1:08	0:59	-1:05-3:22	1:03	1:00	-1:13-2:49
CBTmin	2:26	1:20	-0:42-5:43	2:41	1:15	-0:48-5:36

Note. Phase is measured in 24-hour clock time; Phase angle is measured in hours and minutes and refers to the interval between the phase marker and habitual sleep time (DLMO) or wake time (CBT). The final sample consisted of 166 participants as two cases (1 Man, 1 Woman) were removed due to outlying values on both measures of phase.

$\uparrow$ Scores on this variable in Table 1 reflect Disconstraint. This is the direction in which the variable is measured on the PSY-5 instrument and is presented this way in order to facilitate comparison with normative scores. In all subsequent analyses, interpretation of this variable is reversed so that higher scores indicate greater levels of Constraint.

Table 2

Correlations between PSY-5, MEQ, and circadian variables

	2	3	4	5	6	7	8	9	10
1. Negative Emotionality	-.17*	.11	-.06	.41***	-.12	-.06	-.08	-.03	-.05
2. Positive Emotionality	-	.29**	.11	-.04	.06	.13	-.13	.05	-.04
3. Aggressiveness		-	-.27***	.28***	.04	-.04	-.13	-.10	.02
4. Constraint			-	-.15	.22**	-.17*	.01	-.27**	.18*
5. Psychoticism				-	-.07	-.10	.00	-.05	-.03
6. MEQ					-	-.37***	.12	-.40***	.25**
7. DLMO phase						-	-.57***	.76***	-.37***
8. DLMO phase angle							-	-.27**	.53***
9. CBT phase								-	-.74***
10. CBT phase angle									-

* .05

** .01

*** .001