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Cognitive Psychology

Mind-wandering in Larks and Owls: The Effects of Chronotype and Time of Day on the Frequency of Task-unrelated Thoughts

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People differ in their optimal time of day to perform a cognitive task: Morning people ("larks") perform better in the morning compared to the evening, and the reversed is true for evening people ("owls"). This synchrony effect has been observed for executive functions, such as inhibitory control. For example, participants performing the Sustained Attention to Response Task (SART) make more commission errors at their non-optimal time of day. Because mind-wandering (MW) has been related to the executive system, we here investigated a synchrony effect in the frequency of MW. After determining the participants' chronotype (*n* = 130), they completed an online version of the SART twice, once in the morning and once in the evening. MW was subjectively measured using a probe-caught method. Results showed that "larks" mind-wandered more often in the evening than the morning session. In contrast, "owls" showed the opposite profile. Objective markers for MW (i.e., accuracy and reaction time coefficient of variance) confirmed these results. Furthermore, in line with earlier suggestions, the frequency of MW was also directly related to the number of hours slept the night before the experiment, and an overall higher frequency of MW was observed for evening chronotypes. The results of this study provide clear evidence for the relation between sleep-related factors and MW, and raises the importance of accounting for chronotype differences when scheduling work and academic activities.

Introduction

Remaining focused on a task is critical in many situations. Having thoughts that are unrelated to the task at hand is an intrusive phenomenon regardless of the type of task being performed (Killingsworth & Gilbert, 2010; Seli et al., 2018). Task-unrelated thoughts, often referred to as mind-wandering (MW; Smallwood & Schooler, 2006), are known to widely impact behavior. For example, MW has been shown to negatively affect performance in daily-life activities (McVay et al., 2009) such as real-world driving performance (Galera et al., 2012), or learning and retaining of new information in educational settings (Risko et al., 2012; Szpunar et al., 2013). In contrast, MW is less disruptive for behavioral performance in less demanding settings or when the task is highly automatized, and has functional benefits depending on the context (Smallwood & Andrews-Hanna, 2013). It has been shown that MW facilitates creative problem solving (e.g., Baird et al., 2012), and recent suggestions related MW to offline learning episodes (Jubera-Garcia et al., 2021; Wamsley, 2022).

Why MW episodes occur remains unclear but different studies suggested that sleep-related factors influence their frequency (for a review, see Jubera-Garcia et al., 2021). Survey studies have shown a relation between sleep quality and MW (Carciofo et al., 2014), with the number of sleep disturbances being predictive of the number of MW episodes on the following day (Marcusson-Clavertz et al., 2019). In one controlled experiment, sleep-deprived participants reported more MW episodes compared to well-rested participants in a difficult visual search task (Poh et al., 2016). Interestingly, Poh and colleagues (2016) not only probed the content of the participants' thoughts (i.e., where attention was focused; on- or off-task) but added another probe to question their awareness of their thoughts (i.e., whether participants were aware of the focus of their attention). Their results revealed that sleep-deprived participants reported more MW but they also showed less meta-awareness of their task-unrelated thoughts. Together, these re-

a Correspondence concerning this article should be addressed to Filip Van Opstal, University of Amsterdam, the Netherlands (email: f.vanopstal@uva.nl).

b Equal Contribution – in alphabetical order sults suggest that sleep pressure (i.e., the homeostatic need for sleep, or the pressure for sleep that builds up as the time awake increases) not only changes the focus of attention away from the task at hand but also that this change goes by unnoticed.

Sleep, however, is not only regulated by sleep pressure but also by an individual's circadian pacemaker (Borbély et al., 2016). This pacemaker regulates different biological functions (e.g., the core body temperature, the endogenous melatonin secretion) and is highly related to an individual's diurnal preference or chronotype. Morning chronotypes ("larks") show a marked preference for waking up early and find it hard staying awake past their usual bedtime. In contrast, evening chronotypes ("owls") have difficulties getting up in the early morning and prefer staying awake late at night. Intermediate chronotypes fall in between these two extremes and do well at normal office hours but can also maintain a social life in the evenings. It is well-known that an individual's cognitive performance depends on the individual's chronotype (for a review, see Schmidt et al., 2007). More specifically, better performance is observed when tasks are performed at optimal times of day, i.e. in the morning for morning chronotypes and in the late afternoon or evening for evening chronotypes. This so-called synchrony effect (May et al., 1993) has, for example, been shown to be present for executive control, such as the ability to inhibit a response. When participants perform a sustained attention to response task (SART; Robertson et al., 1997) in which they need to respond to a centrally presented digit (ranging from 1 to 9; go trials) but they need to refrain from responding when the digit is the number 3 (no-go trials), morning people make more commission errors (i.e., failures to inhibit a response to a no-go trial) when they perform the SART in the evening compared to the morning, and vice versa for evening people (Lara et al., 2014). A synchrony effect on inhibitory efficiency was also found in a word problem task with irrelevant distractor words having larger effects at the non-optimal time of day (May, 1999), and other tasks that tax the executive system, such as the Stroop task ((Schmidt et al., 2012) or the Wisconsin Card Sorting task (Bennett et al., 2008; but only for morning chronotypes).

Because the executive system is also central in different theories of MW (e.g., McVay & Kane, 2010; Thomson et al., 2015), it could thus be expected that MW is not only related to an increase in sleep pressure, but that MW is also sensitive to the circadian pacemaker. In other words, a synchrony effect should also be present for MW with more MW episodes in the evening for morning chronotypes, and more MW episodes in the morning for evening chronotypes. Although one survey study reported an association between MW frequency and evening chronotypes and MW, whether MW is subject to the synchrony effect has not been experimentally investigated. The main aim of the present study is thus to investigate if the frequency of MW depends on an individual's chronotype and the time of day at which a task is performed. Furthermore, because prior work has shown that homeostatic sleep pressure increases unaware episodes of MW (Poh et al., 2016), we also expect to specifically observe a synchrony effect in unaware MW episodes here.

Methods

Sample size

We used the R package SIMR (Green & MacLeod, 2016) to perform an a priori power analysis for a generalized linear mixed model (GLMM). Data from a pilot study (n = 80) was used to perform an GLMM (i.e., with a Poisson distribution and log link function) on the frequency of MW with a random intercept across participants. The fixed effects were the Chronotype, the Time of Day when the task was performed, their interaction, and the hours of sleep prior to each session. The effect size of the main effect of interest (Chronotype * Time of Day) is the estimate of the effect (i.e., the interaction between Morning and Evening Chronotypes and Time of Day) in the model. It is the unstandardized difference in the slopes of the contrast specified in the model and was equal to -0.25. The power calculations suggested that the pilot sample size has 97.44% power to detect a significant interaction. Increasing the sample size to 150 participants (i.e., 50 participants per chronotype) would lead to 100% power to detect a significant interaction. Although it could be argued that setting the sample size this large is overpowering the study, calculating the required sample size based on a pilot study with a small sample size might bias the estimate of the effect size and hence lead to underpowered main studies (Albers & Lakens, 2018).

Participants

All participants were students at the University of Amsterdam that participated for course credits. Of the 168 participants that completely filled out the MEQ[1], 18 participants declined to further participate in the study. Of the remaining 150 participants, 20 participants failed to complete the two sessions because of an unstable internet connection. The final sample thus consisted of 130 participants (mean age: 20.65, range: 18-38; 96 females, 33 males and one non-binary), of which 52 were classified as Evening types, 56 as Intermediate types, and 22 as Morning types (Table 1). The study was approved by the local ethical committee and all participants gave their informed consent prior to the experiment.

1 Another 52 participants filled out the MEQ but because they were all intermediate or evening chronotypes, they were excluded to further participate in the experiment. We failed to find additional morning types among our participant population (i.e., students at the University of Amsterdam).

Table 1. Descriptives for different chronotype groups

	Chronotype		
	Morning	Intermediate	Evening
N	22	56	52
Mean Age (Stdev)	22.3 (4.94)	20.4 (2.12)	20.3 (1.79)
Minimum/Maximum Age	18/38	18/28	18/26
Male/Female/Non-binary	5/17/0	12/43/1	16/36/0
MEQ scores (Stdev)	64 (3.95)	49.64 (5.11)	35.6 (4.25)
Sleep duration (Stdev)	7.59 (1.03)	7.30 (1.13)	6.68 (1.35)

Stimuli and apparatus

Morningness-Eveningness Questionnaire (MEQ). The MEQ (Horne & Östberg, 1976) consists of 19 multiple choice questions, with each answer option being assigned a value between 1 and 4 or 5. Values add up to a score ranging from 16-86, with lower values indicating eveningness. Based on their score, participants can be divided into five chronotypes: Definitely evening (16-30), Moderately evening (31-41), Intermediate (42-58), Moderately morning (59-69), Definitely morning (70-86). Similar to previous research using the MEQ (Carciofo et al., 2014), we will merge the two evening and morning types, resulting in three categories: Evening, Intermediate, and Morning type. The MEQ has been shown to be highly reliable across countries (Di Milia et al., 2013) and its validity has been demonstrated using different subjective and objective indicators (Bailey & Heitkemper, 2001).

In addition to the MEQ, we also asked how many hours participants slept the night before performing the experimental session.

Sustained Attention to Response Task (SART). Participants performed two sessions of the SART (Robertson et al., 1997), each session on a different day (see *Procedure*). During the SART, digits ranging from one to nine were presented at the center of the screen for 700 ms, followed by a fixation cross that was presented for 2000 ms. Participants were asked to press the space bar as fast as possible when a stimulus was presented (go-trials), but to refrain from responding when the stimulus was the number 3 (no-go trials). A session of the SART contained 600 trials. A short exercise block of 12 trials preceded the first experimental session during which participants received feedback about their accuracy. Throughout the SART, 40 thought probes were presented at pseudorandom timepoints (every 11-18 trials, which corresponds to a probe every 30 to 49s, similar to e.g., Jubera-García et al., 2020; Unsworth & Robison, 2018) with the goal of determining what the attentional state of the participant was. Participants were asked the following question: "Where was your attention focused before the presentation of this question?". Three response options were available: (1) On-task, (2) Aware Off-task, and (3) Unaware Off-task. A detailed explanation of the different response options was given to the participants prior to the experiment (see Appendix 1). All the stimuli and text were presented in black on a white background. One experimental session lasted about 45 minutes. The experiment was programmed in Neurotask (Neurotask BV; https://www.neurotask.com).

Procedure

After registering for the experiment via the university lab website, participants would receive a digital version of the MEQ. Based on the scores of the MEQ, participants were categorized as morning, intermediate or evening types. Participants were asked to perform two sessions of the SART, one in the morning (at 8 AM) and one in the evening (at 8.30 PM). The time between the two session ranged from five to 10 days. On the date of the experiment, participants were invited to a Zoom session in which they received verbal instructions and could ask additional questions. They were then assigned to individual break-out rooms to perform the SART. Before the start of the experiment, participants answered the question about how many hours they slept the previous night and again received written instructions. The time of day (i.e., morning or evening) at which the experiment was performed was counterbalanced within every chronotype group.

After the last experimental session, participants were asked about their awareness of the experimental manipulation to be able to control for demand characteristics. Participants had to respond to two questions: "What do you think the goal of this study is?", and "What are the exact expectations?". Participants were left entirely free to formulate and write down a response.

Results

To test whether the chronotype and time of day are related to the propensity to MW, a generalized linear mixed model (GLMM; with Poisson distribution and log link function) analysis was performed on the responses to the thought probes. The model's fixed effects included Chronotype (Morning, Intermediate, and Evening), Time of Day (Morning or Evening), the interaction between Chronotype and Time of Day, and the number of hours slept prior to the experiment. The subject was added as a random factor. The dependent variable was the frequency of MW episodes (i.e., the number of Off-task responses out of the total number of thought probes). Frequentists analyses were complemented with Bayesian generalized linear mixed-effect models (BGLMM) with uninformative priors, both conducted in JASP (JASP Team, 2022). Estimated contrast parameters with 95% highest posterior density interval (HPDI) that did not contain 0 are considered to support the presence of an effect because the probability that the parameters contribute to the statistical model is 95%. The analyses revealed a main effect of number of hours slept, $\chi^2(1) = 13.50$, $p < .001$, $\beta = -0.06$ ($\beta_{Sleep} = -0.06$, *HPDI* = [-0.10, -0.3]), indicating that participants reported more MW episodes when they slept less the night before the experiment. The main effect of Chronotype was also significant, $\chi^2(2) = 7.10$, $p = .029$. Planned contrasts (*p*-values adjusted using Holm adjustment) showed that both the difference between Morning and Evening chronotypes, and between Intermediate and Evening chronotypes were close to significance for the frequentist analysis ($z = -2.21$, $p_{Holm} = .067$, and $z = -2.29$, $p_{Holm} = .067$). Bayesian analysis showed that these differences were reliable: $\beta_{Evening\text{-}Morning} = 9.22$, *HPDI* = [0.65, 17.58] , and $\beta_{Evening\text{-}Intermediate} = 7.65$, *HPDI* = [1.31, 14.77] (the Estimated Marginal Means for the MW ratio are 21.39, 17.63 and 16.64 for the Evening, Intermediate, and Morning chronotypes; Figure 1A). Most importantly, the critical interaction between Chronotype and ToD was significant, $\chi^2(2) = 32.65$, $p < .001$, and is presented in Figure 1B. Planned comparisons indicated that the MW count was significantly higher in the evening compared to the morning session for Morning chronotypes, $z = 4.32$, $p_{Holm} < .001$, $\beta = 5.65$ ($\beta_{Morning\ Chronotype\ (Evening\ session\ -\ Morning\ session)} = 5.62$, *HPDI* = [3.06, 8.36]). For the Evening chronotypes, a significant difference in the opposite direction was found, $z = -3.13$, $p_{Holm} = .007$, $\beta = -3.12$ ($\beta_{Evening\ Chronotype\ (Evening\ session\ -\ Morning\ session)} = -3.11$, *HPDI* = [-5.16, -1.32]), with a higher MW count in the morning compared to the evening session. No difference between the morning and evening session was observed for the Intermediate chronotypes, $z = -0.57$, $p_{Holm} = .566$ ($\beta_{Intermediate\ Chronotype\ (Evening\ session\ -\ Morning\ session)} = -0.46$, *HPDI* = [-1.98, 1.22]) (Figure 1B).

Because prior work suggested that sleep-related factors are more related to unaware MW episodes rather than aware MW episodes, the main GLMM was performed again but on the count of unaware MW (i.e., the number of Unaware Off-task responses out of the total number of thought probes). This analysis again revealed a main effect of Chronotype, $\chi^2(2) = 7.01$, $p = .030$, and an interaction between Chronotype and Time of Day, $\chi^2(2) = 40.40$, $p < .001$ $p < .001$, with a similar pattern of results: Morning chronotypes showed significantly less unaware MW during the morning session compared to the evening session, $z = 3.34$, $p_{Holm} = .003$, $\beta = 2.92$ ($\beta_{Morning\ Chronotype\ (Evening\ session\ -\ Morning\ session)} = 2.86$, *HPDI* = [1.28, 4.74]), and Evening chronotypes showed significantly more unaware MW during the morning session compared to the evening session, $z = -4.15$, $p_{Holm} < .001$, $\beta = -2.62$ ($\beta_{Evening\ Chronotype\ (Evening\ session\ -\ Morning\ session)} = -2.55$, *HPDI* = [-3.87, -1.39]) . No difference was observed for the Intermediate chronotypes, $z = -0.61$, $p_{Holm} = .95$ ($\beta_{Intermediate\ Chronotype\ (Evening\ session\ -\ Morning\ session)} = -0.20$, *HPDI* = [-0.92, 0.50]). The interaction between Chronotype and Time of Day was also observed when the same analysis was performed on the count of aware MW (i.e., the number of aware Off-task responses out of the total number of thought probes), $\chi^2(2) = 6.14$, $p = .046$. However, the difference between the morning and evening session was only close to significance for the Morning chronotypes, $z = 2.48$, $p_{Holm} = .066$, $\beta = 2.31$ (but reliably different in the Bayesian analysis: $\beta_{Morning\ Chronotype\ (Evening\ session\ -\ Morning\ session)} = 2.27$, *HPDI* = [0.48, 4.22]). No difference was observed for the Evening chronotypes ($z = -0.22$, $p_{Holm} = 1$; $\beta_{Evening\ Chronotype\ (Evening\ session\ -\ Morning\ session)} = -0.13$, *HPDI* = [-1.39, 1.20]), and Intermediate chronotypes ($z = -0.21$, $p_{Holm} = 1$; $\beta_{Intermediate\ Chronotype\ (Evening\ session\ -\ Morning\ session)} = -0.12$, *HPDI* = [-1.34, 1.13]).

Participants had to fill out the MEQ prior to participating in the experiment which might have caused partial awareness about the research question. To rule out the potential influence of demand characteristics, we performed three additional control analysis. In the first two analysis, we validated the subjective response to the thought probes by looking at their relation to objective markers of MW. *First*, we looked at the reaction time coefficient of variance (RTCV) that has been consistently shown to be related to MW (Bastian & Sackur, 2013; Cheyne et al., 2009; Groot et al., 2021; Jubera-García et al., 2020). The RTCV was calculated by taking the standard deviation of eight trials before a thought probe (excluding error trials and no-go trials), divided by their mean. In line with previous work, an linear mixed model (LMM) on the RTCV with the response to the thought probe (i.e., On-task or Off-task) as a fixed factor and participant as a random factor showed a significant effect of mind-wandering on the RTCV, $F(1, 133.55) = 6.00$, $p = .016$, $\eta_p^2 = .04$ ($\beta_{Off\text{-}task\ -\ On\text{-}task} = -0.\text{-}16$, *HPDI* = [-0.02, -0.01]), with a higher RTCV when subjects report having task-unrelated tasks (.204 and .220 for On-task and MW episodes, respectively). *Second*, A similar analysis on the accuracy of the trial preceding a thought probe revealed that more failures to inhibit a response were made when participants reported task-unrelated thoughts (7.3 %) compared to On-task thoughts (3.6 %), $F(1, 128.9) = 36.75$, $p < .001$, $\eta_p^2 = .22$ ($\beta_{Off\text{-}task\ -\ On\text{-}task} = 0.04$, *HPDI* = [0.03, 0.05]) (Groot et al., 2021; McVay & Kane, 2010). In a final control analysis, participants were categorized as aware or unaware participants based on their response to the awareness question at the end of the final experimental session (see Appendix 2 for the categorization criteria) by two raters (V.A. and S.S.). One participant did not respond to the awareness questions and was removed from this analysis. Cohen's κ coefficient was calculated to measure the inter-rater reliability and was found to be almost perfect ($\kappa = 91.73\%$). The main GLMM analysis was performed again twice, once for each rater, with the factor Awareness added as a fixed factor. Results showed no interaction between Awareness and the critical interaction between Chronotype and Time of Day (all *p*'s > .214) indicating that awareness of the research question was not critical to obtain our main result.

Discussion

The results of this experiment show a clear synchrony effect on the frequency of MW: Morning chronotypes report more MW episodes in the evening compared to the morning and vice versa for the evening chronotypes. No difference in time of day was observed for the intermediate chrono-

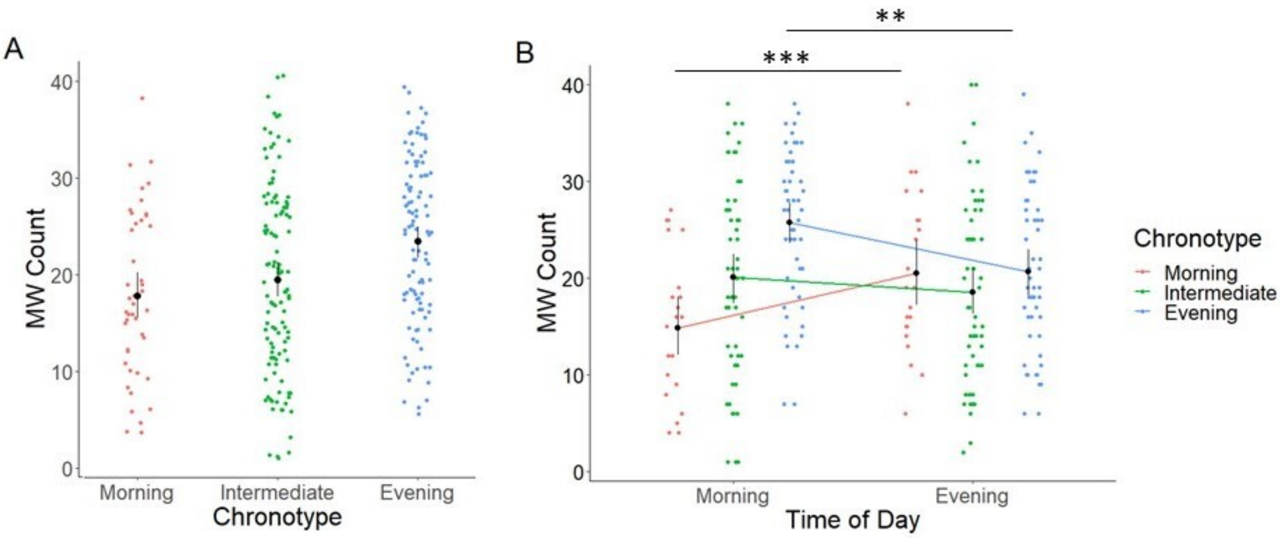

Figure 1. (A) Evening chronotypes mind-wander more compared to Morning and Intermediate chronotypes. (B) The interaction between the chronotype and the time of day at which the SART was performed showed that participants mind-wander less at their optimal time of day. The MW count was significantly smaller in the morning compared to the evening for morning chronotypes. For evening chronotypes, a significant reversed result was found. For intermediate chronotypes, no difference in mind-wandering is found between the morning and evening session. Error bars denote 95% confidence intervals. ** = $p < .01$, *** = $p < .001$

types. Importantly, behavioral results from the SART (i.e., RTCV and accuracy) and post-experimental queries ruled out a potential influence of demand characteristics. Our results furthermore showed that evening chronotypes tend to MW more compared to other chronotypes and that there is a direct effect of the hours slept the night before the experiment on the frequency of MW.

The synchrony effect in MW observed here resonates with earlier results showing a synchrony effect in response inhibition in the SART (Lara et al., 2014). Lara and colleagues showed that more commission errors were made when there was a mismatch between the time of day and the individual's chronotype, indicating circadian influences on inhibitory control. Our results replicate these findings by showing that commission errors are related to MW and that MW is sensitive to an individual's circadian rhythm. According to an inhibitory framework of circadian effects on behavioral performance (Hasher et al., 1999), the increase in MW episodes at non-optimal times of day could directly be related to an increased failure to inhibit irrelevant information from internal sources. This view would be in line with theoretical proposals that relate the initiation of MW episodes to failures in executive control (McVay & Kane, 2010; Smallwood, 2013), and with recent empirical work showing a relation between sleep-like activity (i.e., slow-wave activity in the theta range) over the frontal areas of the brain, response inhibition, and MW (Andrillon et al., 2021). When an individual performs a task at a non-optimal time of day, the sleep-promoting signals from the circadian pacemaker might be evoking more local sleep-like activity in the executive system and hence induce more MW and commission errors. Following previous work showing that sleep-deprivation decreases awareness of MW episodes (Poh et al., 2016), it was expected that a synchrony effect would be more pronounced for unaware MW. Contrary to our expectations, however, a synchrony effect was observed for both unaware and aware MW although planned comparisons showed a difference for Morning and Evening chronotypes only for unaware MW; only the Morning chronotypes showed an effect of Time of Day for aware MW. The prediction that sleep pressure is mostly related to unaware MW also follows from a recent suggestion relating local resource depletion to MW (Jubera-García et al., 2021, 2021). According to that suggestion, the local depletion of resources will increase local sleep pressure and hence increase the probability for MW to occur (Andrillon et al., 2021). Because local resource depletion is an inevitable biological consequence of neural activity, this suggestion would mainly concern the type of MW that is beyond the individual's control, intention, or awareness. Future work is needed to further clarify how an increase in sleep pressure relates to different types of MW, and how MW might serve a restorative function.

Because this experiment was performed online, with participants participating from home, it could be argued that the results might be caused by environmental differences between morning and evening sessions across groups. It should be noted, however, that data collection took place in the Netherlands in the months of April and May, meaning that the morning session were performed after sunrise and the evening sessions before sunset. Participants performed the experiment while being monitored in individual break-out rooms in Zoom. This means that we could monitor their behavior (i.e., phones on airplane mode, being in a room alone, etc.), but also that we could not fully control the environment and location participants were in. However, because participants were performing the

SART sessions in their own environment, it is unlikely that there would be consistent environmental differences between the morning and evening session across the group of participants. In fact, we would argue that the random variation in the participants' environment makes the presence of a synchrony effect even more impressive: random noise that could have been introduced by changes in the environment between morning and evening sessions did not obscure the modulation of MW frequency with time of day.

Similar to a survey study on Chinese volunteers (Carciofo et al., 2014), our results also showed that evening chronotypes MW more compared to other chronotypes. Earlier results showing a synchrony effect for response inhibition also showed overall worse performance for the evening types (Lara et al., 2014). Because of the supposed relation between the executive system and MW, together these results suggest that the executive system is particularly prone to temporary failures in evening chronotypes. Whether this difference in executive system functioning between chronotypes is caused by differences in personality traits (Finomore et al., 2009), sleep efficiency (Lehnkering & Siegmund, 2007; Taillard et al., 1999), or the availability of cognitive resources (Jubera-García et al., 2021; Nowack & Van Der Meer, 2018) cannot be answered by this study.

Our results furthermore showed that the frequency of MW is directly related to the number of hours slept the night before the experiment. Irrespective of the chronotype or the time of day at which the experiment was performed, the smaller the number of hours slept, the more MW during the SART. This result is also analogous to earlier results showing that subjects with more nightly sleep disturbances (Marcusson-Clavertz et al., 2019), or sleep-deprived subjects (Poh et al., 2016), show more MW episodes. The results of this study therefore not only evidence a relation between the circadian rhythm and MW, but also between homeostatic sleep pressure and MW.

Although the main effect of number of hours slept on the frequency of MW is in line with previous work, one of the limitations of the present study is that this analysis is based on subjective reports only. Participants were asked to follow their usual sleep habits throughout the study and to report the number of hours slept the night before the experiment, but we lack an objective control or measurement. A second limitation concerns the unequal distribution between the different chronotype groups. Although the post-hoc power analysis indicates that the sample size was sufficiently large in all groups, we did not manage to reach the required number of morning chronotypes and the final sample of this group is rather small. This is most likely due to the fact that all participants were young adults at an age at which evening chronotypes are much more dominant than morning chronotypes (e.g., Randler et al., 2017; Roenneberg et al., 2004). Interestingly, our failure to find the a priori defined number of morning chronotypes highlights the importance of the main results of this study. Only 22 out of the 230 students who filled out the MEQ for this study were morning chronotypes but all of them undergo social obligations because of their academic curriculum. Given that MW tendency is associated with poor cognitive performance (e.g., Smallwood & Schooler, 2006) and that the morning chronotype is under-represented in (under)graduate population, the planning of academic activities, especially those that have a substantial impact on students' future possibilities (e.g., exams), should be considered very carefully. Obviously, this practical implication resulting from this study does not only apply in academic settings, but also in other work-related and everyday situations where optimal cognitive functioning is critical.

Author Contributions

F.V.O. developed the study concept. All authors contributed to the study design. V.A. and S.S. collected the data. V.A. and S.S. performed the data analysis and interpretation under the supervision of F.V.O. All authors drafted the manuscript and approved the final version of the manuscript for submission.

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Competing Interests

The authors declare that there are no conflicts of interest.

Data Accessibility Statement

The study design, data-analyses and expected results were publicly preregistered at https://osf.io/7gh6j. All data, analysis scripts and results can be found can be found at https://osf.io/nbm8g/.

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Appendices

Appendix 1: Detailed Instructions to Participants about Their Responses to the Thought Probes

While you are completing this task, you may find yourself thinking about things other than the task. These thoughts are referred to as 'mind-wandering'. Mind-wandering is perfectly normal, especially when one must do the same thing for a long period of time. We would like to determine how frequently you were thinking about the task versus how frequently you were thinking about something unrelated to the task (mind-wandering). To do this, every once in a while, the task will temporarily stop, and you will be presented with a thought-sampling screen that will ask you to indicate where your thoughts were.

The thought-probes will present the following question: Where was your attention focused just before the probe? You will be given three response options (On-Task, Aware Off-Task, Unaware Off-Task).

1. Choose the first option (On-Task) when you were fully attending to the task right before the question was presented.
2. Choose the second option (Aware Off-Task) when you are thinking about something else than the task before the question was presented. Here, you are aware that your mind has drifted from the task, but for some reasons you still continue to attend to the task. This is what we refer as "aware off-task thoughts" – i.e., when your mind wanders, and you know it all along.
3. Choose the third option (Unaware Off-Task) when you are thinking about something else than the task before the question was presented. Here, you don't realize that your thoughts have drifted away from the task until you catch yourself. This is what we refer to as "unaware off-task thoughts"—i.e., when your mind wanders, but you don't realize this until you catch it.

Appendix 2: Awareness about the Experimental Manipulation

"What do you think the goal of this study is? What are the exact expectations?" Aware participants were classified if the answers to the question included:

- As IV: the interaction effect (Time of Day & Chronotype), or synonyms such as: preferred the of the day, optimal time of the day; • As DV: MW, attention levels, on-task/ off-task.
- As IV: the interaction effect (Time of Day & Chronotype), or synonyms such as: preferred the of the day, optimal time of the day; • As DV: Performance, Reaction Times.

Unaware participants were classified if the answers to the question included:

- As IV: either the Time of Day or the Chronotype, but no interaction effect. • As DV: MW, attention levels, on-task/ off-task, Performance, Reaction Times.
- Those participants who do not fulfil any of the abovementioned criteria.

Supplementary Materials

Peer Review History

Download: https://collabra.scholasticahq.com/article/57536-mind-wandering-in-larks-and-owls-the-effects-of-chronotype-and-time-of-day-on-the-frequency-of-task-unrelated-thoughts/attachment/123008.docx?auth_token=kcsC9cRnpWPxFWmtsJ5H