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Evening use of caffeine moderates the relationship between caffeine consumption and subjective sleep quality in students

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Summary

Caffeine is often used to reduce sleepiness; however, research suggests that it can also cause poor sleep quality. The timing of caffeine use, amongst other factors, is likely to be important for the effects it has on sleep quality. In addition, individual differences exist in the effect of caffeine on sleep quality. This cross-sectional study investigated the influence of the timing of caffeine consumption on and a possible moderating role of chronotype in the relationship between caffeine consumption and sleep quality in 880 students (74.9% female, mean age 21.3 years, SD = 3.1). Respondents filled in online questionnaires about chronotype (the Morningness–Eveningness Questionnaire), sleep quality (the Pittsburgh Sleep Quality Index) and caffeine consumption. Mean caffeine consumption was 624 mg per week, and 80.2% of the sample drank caffeine after 18:00 hours. Regression analyses demonstrated that higher total caffeine consumption was only related to poorer sleep quality for people who did not drink caffeine in the evening ($\beta = 0.209$, $p = .006$). We did not find a relationship between caffeine and sleep quality in people who drank caffeine in the evening ($\beta = -0.053$, $p = .160$). Furthermore, we found no evidence for a moderating role of chronotype in the relationship between caffeine consumption and sleep quality. We concluded that a self-regulating mechanism is likely to play a role, suggesting that students who know that caffeine negatively affects their sleep quality do not drink it in the evening. Caffeine sensitivity and the speed of caffeine metabolism may be confounding variables in our study.

KEYWORDS
caffeine, chronotype, sleep quality, students

1 | INTRODUCTION

Caffeine is the most used psychoactive substance worldwide, mostly consumed via coffee, energy drinks, tea and chocolate (Fredholm, Battig, Holmen, Nehlig, & Zvartau, 1999). Caffeine generally increases alertness and reduces sleepiness; however, it can also have negative effects on sleep quality. In a recent review, the majority of experimental studies indicated that caffeine consumption negatively affected sleep latency, sleep duration and sleep efficiency, and the relative time spent in deep sleep (Clark & Landolt, 2017).

Large individual differences exist in the speed of caffeine metabolism. The half-life of caffeine ranges from 2.7 to 9.9 hr (Blanchard & Sawers, 1983). Evening use of caffeine, resulting in higher concentrations of caffeine in the blood at bedtime, is likely related to more sleep difficulties, as has been demonstrated in experimental studies (Clark & Landolt, 2017) and the few studies that simulated naturalistic intake patterns (Drake, Roehrs, Shambroom, & Roth, 2013; Hindmarch et al., 2000; Shilo et al., 2002). In another experimental study, people who considered themselves sensitive to caffeine consumed 1 cup of coffee at dinner. This resulted in poorer sleep quality, increased sleep latency and waking up more often at night (Lloret-Linares et al., 2012).

Another factor that influences sleep quality is chronotype, which reflects a person's natural preferred sleep–wake pattern; it influences preferred bedtimes and times of waking up, but also optimal timing of activities and vigilance during the day (Roenneberg, Wirz-Justice, & Merrow, 2003). Evening types report more sleep problems than earlier types (Giannotti, Cortesi, Sebastiani, & Ottaviano, 2002). Evening types are also more likely to consume caffeine to cope with sleepiness (Giannotti et al., 2002) and to consume caffeinated beverages at night (Digdon & Rhodes, 2009). Chronotype may interact with caffeine consumption to affect sleep quality. In an experiment in which participants received a dose of caffeine equivalent to a double espresso 3 hr before bedtime for approximately 49 days, the circadian melatonin rhythm was delayed by approximately 40 min at the end of the trial. In vitro exposure of human cells to caffeine also resulted in a lengthened cellular circadian clock (Burke et al., 2015). Because the circadian rhythm is already delayed in later chronotypes (Duffy, Rimmer, & Czeisler, 2001), a larger delay could exert even more negative effects on sleep quality, whereas the advanced circadian rhythm in morning types could act as a buffer against the effects of caffeine; this would lead to a stronger negative relationship between caffeine consumption and sleep quality in later chronotypes.

To our knowledge, only one study has been published on the interaction of caffeine and chronotype in their relationship with sleep quality (Nova, Hernandez, Ptolemy, & Zeitzer, 2012). In this study in 50 university students, no significant relationship was found between estimated caffeine concentrations at bedtime and wakefulness after sleep onset. However, with chronotype as a moderator, the positive relationship between caffeine concentration and wakefulness was significant and strong in morning types, moderate in intermediate types, and non-existent in evening types (Nova et al., 2012).

Because sleep difficulties are common among students, with a prevalence of poor sleepers reaching up to 60% (Lund, Reider, Whiting, & Prichard, 2010), research on predictors of sleep quality in students is warranted. This study aims to investigate the relationship between caffeine consumption and sleep quality in students, and whether this relationship is moderated by the timing of caffeine consumption or chronotype.

2 | MATERIALS AND METHODS

2.1 | Participant recruitment and procedure

This study was conducted among Dutch-speaking university and other tertiary education students (full-time or part-time), aged 18 years and older. In total, 1,041 students were recruited through advertisements on social media and by distributing flyers at universities in several Dutch cities for 1 month during March 2014 ($N = 154$), March 2016 ($N = 463$) and March 2017 ($N = 424$). Respondents who did not meet the inclusion criteria of being both 18 years or older and a student, and who did not complete the relevant questionnaires for this study, were excluded from our sample. The analyses were conducted on the remaining sample of 880 participants. To participate in the study, respondents received a link to access the online questionnaires. First, they were informed, in general terms, about the purpose of the study. Respondents could participate in a lottery, in which they could win €50, €25 or €10. They were asked to provide their informed consent by clicking the "agreement" button. The Leiden University's Psychology Research Ethics Committee approved the study.

2.2 | Measures

2.2.1 | Sleep quality

We used the Dutch translation of the Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989) to measure sleep quality. The PSQI consists of 19 self-report questions about sleep habits during the past month. It can be divided into seven components: subjective sleep quality; sleep latency; sleep duration; habitual sleep efficiency; sleep disturbances; use of sleeping medication; and daytime dysfunction. Overall scores range from 0 (no difficulty sleeping) to 21 (severe difficulties). A score > 5 indicates clinically significant sleep problems (Buysse et al., 1989).

2.2.2 | Caffeine consumption

Caffeine use was measured with a questionnaire about substance use during the past month. The substance-use questionnaire contained seven questions about alcohol, caffeine, tobacco and cannabis use. Only the questions that address caffeine use were used in this study. We asked respondents to report their average frequency of coffee, tea, cola or energy-drink consumption per week during different times of day: morning (06:00–12:00 hours); afternoon (12:00–18:00 hours); evening (18:00–02:00 hours); and night (02:00–06:00 hours).

Coffee, tea, cola and energy drinks contain different amounts of caffeine per portion. We used a conversion table from the Netherlands Nutrition Centre to calculate the total consumed amounts of caffeine per week (http://www.voedingscentrum.nl/encyclopedie/cafeine). Based on this table, we assumed that each cup of coffee contained 85 mg of caffeine, each cup of tea 30 mg, each serving of cola 18 mg, and each serving of energy drink 80 mg.

To assess whether participants consumed caffeine in the evening, a dichotomous variable was created: respondents who reported drinking at least one caffeinated beverage in the evening (i.e. between 18:00 hours and 02:00 hours) received a score of 1 (=yes) on this variable. A score of 0 (=no) was assigned when respondents did not consume any caffeine in the evening. When participants consumed caffeine at night but not in the evening, they also received a score of 0 because this time interval does not allow us to conclude whether the caffeine was consumed late at night before bedtime, or early in the morning after waking up.

2.2.3 | Chronotype

The Dutch translation of the Morningness–Eveningness Questionnaire (MEQ; Horne & Östberg, 1976) was used to measure chronotype. The MEQ is a self-report questionnaire consisting of 19 multiple-choice questions about preferred times of going to bed and waking up, ease of waking up in the morning and preferred moments to do certain activities. The total score ranges from 16 to 86, with higher scores indicative of an earlier circadian typology.

2.3 | Data analysis

Descriptive analyses were performed on demographics and key variables. Chronotype, sleep quality and total weekly caffeine consumption were used as continuous variables, while "Evening use of caffeine" (yes/no) was a dichotomous variable. For each analysis, we checked potential confounders (sex, age, alcohol consumption, and cannabis use) for univariate associations with the outcome variable, and only included the variables that were significantly associated with the outcome variable in the multivariate model. First, we used a multiple regression analysis (MRA) to investigate whether caffeine consumption was associated with sleep quality. Second, we performed an MRA to investigate whether the use of caffeine in the evening was a moderator in the relationship between caffeine consumption and sleep quality. Third, we used an MRA to examine whether chronotype moderated the relationship between caffeine consumption and sleep quality. Finally, we performed an MRA to investigate whether chronotype is a moderator in the relationship between evening use of caffeine and sleep quality, adjusted for total weekly caffeine consumption. A significance level of $\alpha = 0.05$ was used for all statistical analyses, which were performed using IBM SPSS Statistics for Windows, Version 22.0 (IBM, Armonk, NY, USA).

3 | RESULTS

The final sample consisted of 880 participants, 659 women (74.9%) and 221 men (25.1%). Clinically significant sleep difficulties, which are indicated by a PSQI score > 5, were present in 39.4% of the students. On average, students consumed 5.2 ($SD = 6.9$) glasses of alcoholic beverage per week. Only 40 students (4.5%) reported using cannabis, ranging from 1 to 16 joints per week. Table 1 presents participant demographics and scores on the key variables.

Univariate analyses showed that of the potentially confounding variables (sex, age, alcohol consumption, and cannabis use), only alcohol consumption was associated with sleep quality ($\beta = 0.077$, $p = .022$). Therefore, we included alcohol consumption in the multivariate regression analyses.

Total weekly caffeine consumption was not associated with sleep quality, adjusted for alcohol consumption ($\beta = -0.007$, $t = -0.216$, $p = .829$; $R^2 = .006$, $F_{2,877} = 2.659$, $p = .071$). We found a significant interaction effect of the use of caffeine in the evening and total weekly caffeine consumption on the relationship with sleep quality ($\beta = -0.362$, $t = -3.303$, $p = .001$). Table 2 lists the results of this analysis.

TABLE 1 Demographics and scores on key variables[a]

	Total sample (N = 880)
Age (years)	21.3 ± 3.1
Sex, female	659 (74.9)
Education level	
Intermediate vocational education	19 (2.2)
Higher vocational education	168 (19.1)
University education	693 (78.8)
Alcohol consumption (glasses per week)	5.2 ± 6.9
Cannabis use (joints per week)	0.19 ± 1.3
Evening use of caffeine, yes	706 (80.2)
Total weekly caffeine consumption (mg)	624 ± 750
Chronotype (MEQ score)	46.5 ± 9.9
Sleep quality (PSQI score)	5.4 ± 2.6

MEQ, Morningness–Eveningness Questionnaire; PSQI, Pittsburgh Sleep Quality Index.
[a]Data are presented as numbers (%) or mean ± standard deviation.

To further investigate this interaction, the sample was divided into two subgroups: students who used caffeine in the evening; and students who did not. An independent samples t-test indicated that total caffeine consumption was significantly higher in students who drank caffeine in the evening (M = 712 mg, SD = 768) compared with students who did not (M = 268 mg, $SD = 543$; $t_{364.037} = -8.821$, $p < .001$). The subgroups did not differ in terms of sleep quality ($t_{878} = -0.744$, $p = .457$) or chronotype ($t_{237.910} = 1.886$, $p = .061$).

A regression analysis, conducted separately for the two groups, demonstrated that for students who drank caffeine in the evening, total weekly caffeine consumption was not related to sleep quality ($\beta = -0.053$, $t = -1.406$, $p = .160$). However, for students who did not consume caffeine in the evening, a higher total caffeine consumption was associated with poorer sleep quality ($\beta = 0.209$, $t = 2.794$, $p = .006$). The corresponding unstandardized regression coefficient $b = 0.0011$ indicates that one extra cup of coffee a day (595 mg of caffeine per week) is associated with a 0.67 point increase on the PSQI. The results of these analyses are presented in Table 3. Figure 1 illustrates the different relationships between caffeine consumption and sleep quality for students who consumed caffeine in the evening and those who did not. The exclusion of the three participants who consumed caffeine at night but not in the evening did not change the results.

Finally, to investigate the specific components of sleep quality with which caffeine consumption is associated, we performed post hoc regression analyses with more specific sleep outcomes derived from the PSQI: sleep-onset latency, total sleep time, habitual sleep efficiency and subjective sleep quality rating (PSQI component 1; "During the past month, how would you rate your sleep quality overall?"). We adjusted the analyses for potential confounders only if they were associated with the outcome measure. We found no association of caffeine consumption with sleep-onset latency ($\beta = -0.025$, $t = -0.741$, $p = .459$), total sleep time, adjusted for

TABLE 2 Moderation effect of evening use of caffeine on the relationship between total weekly caffeine consumption and sleep quality, adjusted for alcohol consumption, $N = 880^a$

Predictor	b	SE	β	t	p-value
Total weekly caffeine consumption × evening use of caffeine	−0.001	0.000	−0.362	−3.303	.001
Total weekly caffeine consumption (mg per week)	0.001	0.000	0.313	3.000	.003
Evening use of caffeine, yes	0.547	0.260	0.083	2.106	.035
Alcohol consumption (glasses per week)	0.028	0.013	0.074	2.195	.028

[a]Fit for model $R^2 = 0.019$, $F_{4,875} = 4.165$, $p = .002$; *b* = unstandardized regression coefficient; SE = standard error; and β = standardized regression coefficient.

TABLE 3 Subgroup analyses of total weekly caffeine consumption as a predictor of sleep quality, adjusted for alcohol consumption ($N = 880$)

	Predictor	b	SE	β	t	p-value
Evening use of caffeine ($N = 706$)	Total weekly caffeine consumption (mg)	0.000	0.000	−0.053	−1.406	.160
	Alcohol consumption (glasses)	0.025	0.014	0.070	1.854	.064
No evening use of caffeine ($N = 174$)	Total weekly caffeine consumption (mg)	0.001	0.000	0.209	2.794	.006
	Alcohol consumption (glasses)	0.050	0.038	0.098	1.301	.195

b, unstandardized regression coefficient; SE, standard error; β, standardized regression coefficient.

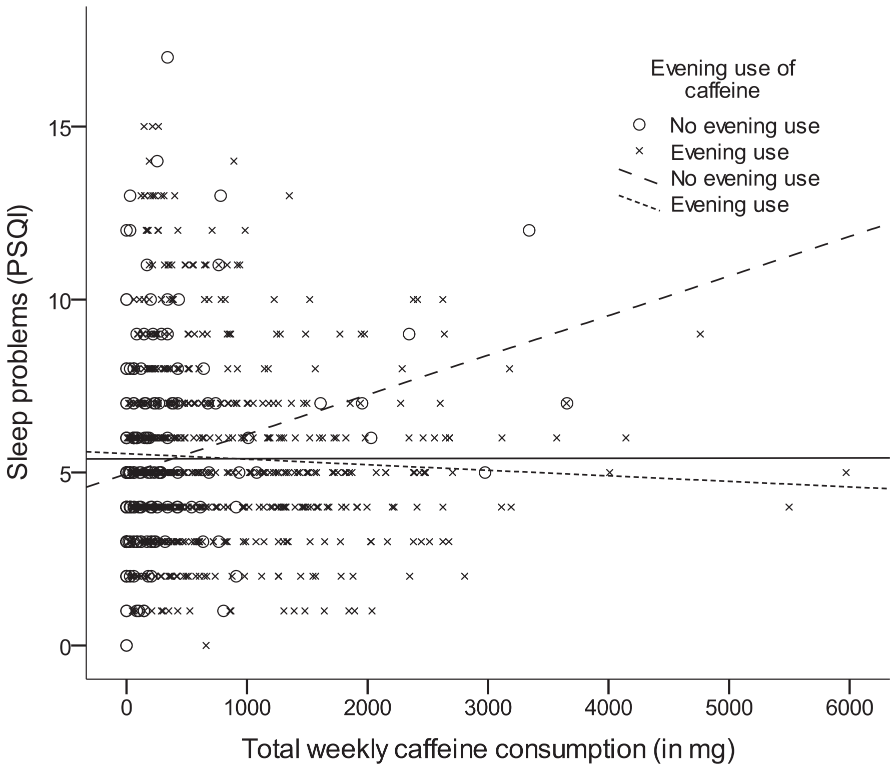

FIGURE 1 Moderation by evening use of caffeine of the relationship between total weekly caffeine consumption and sleep quality. The solid line represents the relationship between caffeine consumption and sleep problems for the total sample. PSQI, Pittsburgh Sleep Quality Index

sex, age, alcohol consumption and cannabis use (β = −0.006, $t = -0.171$, $p = 0.864$), or the subjective sleep quality rating (β = 0.007, $t = 0.193$, $p = .847$). However, caffeine consumption was significantly associated with sleep efficiency, adjusted for sex and alcohol consumption (β = 0.071, $t = 2.135$, $p = 0.033$).

We found no moderation by evening use of caffeine on the relationship between total weekly caffeine consumption and sleep-onset latency (β = −0.139, $t = -1.256$, $p = .209$), or on the relationship between total weekly caffeine consumption and total sleep time, adjusted for sex, age, alcohol consumption and cannabis use (β = 0.090, $t = 0.822$, $p = .412$). Evening use of caffeine also did not moderate the relationship between caffeine consumption and sleep efficiency, corrected for sex and alcohol consumption (β = 0.207, $t = 1.903$, $p = .057$). Furthermore, we found moderation by evening use of caffeine on the relationship between caffeine use and the subjective sleep quality rating, adjusted for sex and age (β = −0.264, $t = -2.401$, $p = .017$). Additional analyses indicate that caffeine consumption was only associated with poorer subjective sleep quality rating in people who do not drink caffeine in the evening (β = 0.170, $t = 2.260$, $p = .025$).

Chronotype was not a moderator in the relationship between total weekly caffeine consumption and sleep quality, adjusted for alcohol consumption ($\beta = 0.025$, $t = 0.191$, $p = .848$). We also did not find moderation by chronotype on the relationship between evening use of caffeine and sleep quality, corrected for alcohol consumption and total weekly caffeine consumption ($\beta = -0.143$, $t = -0.911$, $p = .362$).

4 | DISCUSSION

In this observational study among 880 Dutch students, we investigated the relationship between caffeine consumption and sleep quality, and possible moderation by the timing of consumption and chronotype. Total weekly caffeine consumption was not related to sleep quality in our sample. We found significant moderation by caffeine use in the evening. Higher weekly caffeine consumption was only related to poorer subjective sleep quality for non-evening caffeine consumers, even though their total weekly caffeine consumption was much lower than that of the evening caffeine consumers. Based on our cross-sectional study, we cannot make causal claims. However, caffeine can be used to cope with sleepiness during the day, resulting from poor sleep quality (Giannotti et al., 2002), and caffeine consumption can also decrease sleep quality (Clark & Landolt, 2017). Therefore, the relationship that we found for non-evening caffeine consumers is most likely bidirectional.

Our additional analyses demonstrated that, although higher caffeine intake was related to poorer overall subjective sleep quality in students who did not consume caffeine in the evening, caffeine intake was not associated with total sleep time and sleep-onset latency. This suggests that caffeine may reduce the subjective sleep quality in non-evening caffeine consumers, without evidence of trouble falling asleep or sleeping fewer hours, possibly by a reduction of the relative time spent in deep sleep (Carrier et al., 2006).

Previous experimental research supports a dose–response and timing–response relationship between caffeine intake and sleep quality (Hindmarch et al., 2000). Therefore, it is highly unlikely that evening caffeine use has a smaller effect on sleep quality than daytime caffeine use. A more plausible explanation is that our findings reflect a self-regulating mechanism. Some people may not drink caffeine in the evening because they know it will have adverse effects on their sleep. The average sleep quality did not differ between evening and non-evening caffeine consumers. This suggests that the students who are sensitive to caffeine, i.e. non-evening consumers, may regulate both the timing and amount of caffeine intake in a way that allows them to maintain an acceptable level of sleep quality.

Previous research indicates that individual differences exist in the speed at which the body metabolizes caffeine and in sensitivity to its effects (Blanchard & Sawers, 1983). Experimental research suggested that caffeine caused less sleep disturbance in participants with higher habitual caffeine consumption (Hindmarch et al., 2000). Habitual use can reduce sensitivity to certain effects of caffeine due to tolerance (James, 2014). Caffeine sensitivity is related to, but not a direct reflection of, the speed of metabolism, as the time course of caffeine concentrations was similar in caffeine-sensitive and -insensitive participants (Rétey et al., 2007). Genetics also plays a role in caffeine sensitivity; variations on the adenosine A2A receptor gene (ADORA2A) were related to self-reported sensitivity to caffeine (Rétey et al., 2007). Genetic susceptibility has been associated with subjective and objective (electroencephalogram) sleep-related outcomes when the effect of caffeine was taken into account (Rétey et al., 2005, 2007). The role of the gene has been confirmed in a genome-wide association study of caffeine-related sleep problems (Byrne et al., 2012). Rétey et al. (2007) found that caffeine-sensitive participants consumed less caffeine than caffeine-insensitive participants, and that caffeine consumption was related to insomnia symptoms only in caffeine-sensitive people, which is in line with our findings. However, we did not measure subjective caffeine sensitivity; we only assumed that participants who did not consume caffeine in the evening did so because of previous experiences with caffeine, demonstrating their sensitivity.

This study aimed to replicate the study by Nova et al. (2012) by investigating chronotype as a possible moderator between caffeine consumption and sleep quality. We found that chronotype did not moderate the relationship between caffeine consumption and sleep quality in our sample. Nova et al. (2012) validated the results from their caffeine questionnaire by also analysing caffeine concentrations in saliva samples. In our study, we could not determine caffeine concentration at bedtime.

4.1 | Strengths and limitations

One important strength of our study is its large sample size, resulting in considerable generalizability and large statistical power. In addition, the anonymous online questionnaires reduced the chance of socially desirable answers. Also, our measure of caffeine intake included coffee, tea, cola and energy drinks, whereas in other observational studies often only coffee was measured as a caffeine source (Clark & Landolt, 2017). In addition, we collected data on the timing of caffeine consumption, which is not commonly done in observational studies.

The limitations of our study include its cross-sectional design and the use of only retrospective self-report measures. We asked participants to recall information from the last week up to the past month. Daily diaries of caffeine intake and sleep could have been more accurate measures. Diaries would also have allowed collecting day-to-day data on the timing of caffeine ingestion, and the time interval between last caffeine ingestion and bedtime, which were not available in the current study.

Furthermore, we did not ask participants about the type of coffee they consumed, apart from whether it was decaffeinated or not, or about consumption of chocolate, caffeine supplements and caffeine-containing medication. This may have caused underestimation of caffeine intake in some participants. Finally, we cannot exclude that some of the students had a side job that involved occasional shift work or night-time work. However, as we asked for averages over the last week or month, we assume that the results will reflect "usual" days rather than an occasional day with night work.

4.2 | Future studies

Naturalistic, observational studies are important to examine the effects of caffeine on sleep as they occur in the population. Future observational research on this topic should take caffeine sensitivity and the speed of metabolism into account. Future studies should also utilize a more extensive measure of caffeine consumption, including various types of caffeinated beverages (e.g. the type of coffee), other sources of caffeine, and more precise estimates of quantity and timing of caffeine consumption. Additionally, longitudinal research is needed to examine the direction of the relationship between caffeine consumption and sleep.

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AUTHOR CONTRIBUTION

JvdB designed the study and supervised the project. MK contributed to the data collection, performed the analyses and drafted the manuscript. NA and JvdB critically revised the manuscript. All authors approved the final version.

CONFLICT OF INTERESTS

The authors listed above declare that they have no financial or non-financial interest in the subject matter of the paper.

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REFERENCES

Blanchard, J., & Sawers, S. J. (1983). The absolute bioavailability of caffeine in man. *European Journal of Clinical Pharmacology*, *24*, 93–98.

Burke, T. M., Markwald, R. R., & McHill, A. W. et al. (2015). Effects of caffeine on the human circadian clock in vivo and in vitro. *Science Translational Medicine*, *7*, 305ra146.

Buysse, D. J., Reynolds, C. F., Monk, T. H., Berman, S. R., & Kupfer, D. J. (1989). The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. *Psychiatry Research*, *28*, 193–213.

Byrne, E. M., Johnson, J., McRae, A. F., Nyholt, D. R., Medland, S. E., Gehrman, P. R., … Martin, N. G. (2012). A genome-wide association study of caffeine-related sleep disturbance: confirmation of a role for a common variant in the adenosine receptor. *Sleep*, *35*, 967–975.

Carrier, J., Fernandez-Bolanos, M., Robillard, R., Dumont, M., Paquet, J., Selmaoui, B., & Filipini, D. (2006). Effects of caffeine are more marked on daytime recovery sleep than on nocturnal sleep. *Neuropsychopharmacology*, *32*, 964–972.

Clark, I., & Landolt, H. P. (2017). Coffee, caffeine, and sleep: a systematic review of epidemiological studies and randomized controlled trials. *Sleep Medicine Reviews*, *31*, 70–78.

Digdon, N. L., & Rhodes, S. (2009). Methods used to cope with sleepiness may perpetuate sleepiness in college students with an evening type circadian preference. *Biological Rhythm Research*, *40*, 129–144.

Drake, C., Roehrs, T., Shambroom, J., & Roth, T. (2013). Caffeine effects on sleep taken 0, 3, or 6 hours before going to bed. *Journal of Clinical Sleep Medicine*, *9*, 1195–1200.

Duffy, J. F., Rimmer, D. W., & Czeisler, C. A. (2001). Association of intrinsic circadian period with morningness-eveningness, usual wake time, and circadian phase. *Behavioral Neuroscience*, *115*, 895–899.

Fredholm, B. B., Battig, K., Holmen, J., Nehlig, A., & Zvartau, E. E. (1999). Actions of caffeine in the brain with special reference to factors that contribute to its widespread use. *Pharmacological Reviews*, *51*, 83–133.

Giannotti, F., Cortesi, F., Sebastiani, T., & Ottaviano, S. (2002). Circadian preference, sleep and daytime behaviour in adolescence. *Journal of Sleep Research*, *11*, 191–199.

Hindmarch, I., Rigney, U., Stanley, N., Quinlan, P., Rycroft, J., & Lane, J. (2000). A naturalistic investigation of the effects of day-long consumption of tea, coffee and water on alertness, sleep onset and sleep quality. *Psychopharmacology (Berlin)*, *149*, 203–216.

Horne, J. A., & Östberg, O. (1976). A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *International Journal of Chronobiology*, *4*, 97–110.

James, J. E. (2014). Caffeine and cognitive performance: persistent methodological challenges in caffeine research. *Pharmacology Biochemistry and Behavior*, *124*, 117–122.

Lloret-Linares, C., Lafuente-Lafuente, C., Chassany, O., Green, A., Delcey, V., Mouly, S., & Bergmann, J. F. (2012). Does a single cup of coffee at dinner alter the sleep? A controlled cross-over randomised trial in real-life conditions. *Nutrition & Dietetics*, *69*, 250–255.

Lund, H. G., Reider, B. D., Whiting, A. B., & Prichard, J. R. (2010). Sleep patterns and predictors of disturbed sleep in a large population of college students. *Journal of Adolescent Health*, *46*, 124–132.

Nova, P., Hernandez, B., Ptolemy, A. S., & Zeitzer, J. M. (2012). Modeling caffeine concentrations with the Stanford Caffeine Questionnaire: preliminary evidence for an interaction of chronotype with the effects of caffeine on sleep. *Sleep Medicine*, *13*, 362–367.

Rétey, J. V., Adam, M., Honegger, R., Khatami, R., Luhmann, U. F. O., Jung, H. H., Berger, W., & Landolt, H.-P. (2005). A functional genetic variation of adenosine deaminase affects the duration and intensity of deep sleep in humans. *Proceedings of the National Academy of Science USA*, *102*, 15676–15681.

Rétey, J. V., Adam, M., Khatami, R., Luhmann, U. F. O., Jung, H. H., Berger, W., & Landolt, H.-P. (2007). A genetic variation in the adenosine A2A receptor gene (ADORA2A) contributes to individual sensitivity to caffeine effects on sleep. *Clinical Pharmacology & Therapeutics*, *81*, 692–698.

Roenneberg, T., Wirz-Justice, A., & Merrow, M. (2003). Life between clocks: daily temporal patterns of human chronotypes. *Journal of Biological Rhythms*, *18*, 80–90.

Shilo, L., Sabbah, H., Hadari, R., Kovatz, S., Weinberg, U., Dolev, S., Dagan, Y., & Shenkman, L. (2002). The effects of coffee consumption on sleep and melatonin secretion. *Sleep Medicine*, *3*, 271–273.

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