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What Determines the Effect of Caffeine Upon Memory?

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ABSTRACT

In this paper, we sought to understand what determines whether caffeine affects memory so that we could learn how to use that to our advantage as students. Previous research has found the effect of caffeine upon memory is influenced by variables such as sleep, anxiety, and aerobic exercise. In our correlational study, we tested the strength of these relationships by examining naturalistic daily changes in their variables longitudinally over a period of two weeks. We measured caffeine intake by the total mg of caffeine consumed, sleep duration by the total hours spent sleeping, sleep quality by a subjective scale, anxiety by the State-Trait Anxiety Inventory, exercise duration by the total number of minutes of aerobic exercise, exercise intensity by a subjective scale, and memory performance by the n-back task at the end of each day. Data pooled and standardized across participants in our study showed that memory performance was not significantly correlated with caffeine intake but was significantly positively correlated with sleep duration and significantly negatively correlated with both anxiety and exercise intensity. The relationship between caffeine intake and memory performance was not significantly moderated by any of the study variables except for sleep duration, with memory performance showing a positive relationship with caffeine intake when sleep duration was at below average amounts.

1. Introduction

1.1 Research Problem

Caffeine, a widely known and used stimulant, has gained significant attention from college students due to its perceived influence on cognitive processes, such as memory. Our research problem regards the factors that determine whether caffeine affects our ability to recall and process information. Our rationale for researching caffeine's effects on memory stems from a desire for academic and personal growth. Understanding what determines whethercaffeine impacts memory may help us optimize its use to enhance daily cognitive performance, such as improving focus during work and study. As students, we want to utilize caffeine to enhance focus, but also need to understand what factors could make it could negatively impact memory, which is essential for active listening and maintaining relationships. Gaining insight into this research problem is important because it could reveal when caffeine consumption impacts cognitive functions, potentially helping people make more informed decisions about their daily caffeine intake.

1.2 Literature Review

One factor previously found to influence the effect of caffeine upon memory is sleep. For example, in an experimental study by Onaolapo et al. (2015), adult Swiss Webster mice of both sexes were assigned to six groups, including a vehicle control group and five different doses of caffeine (10, 20, 40, 80, and 120 mg/kg) administered orally for 14 days. Mice were sleep-deprived for 6 hours pre-training and pre-test. Those in the sleep deprivation group underwent "gentle handling" to keep them awake, which involved tapping on the cage and gently touching them. The researchers conducted open-field novel object recognition tests and Y maze spatial working memory tests on day 14. The results indicated that a combination of pre-training and pre-test sleep deprivation alongside caffeine impaired both non-spatial and spatial memory in male and female mice. In the vehicle control group (non-sleep-deprived and not given caffeine), memory performance remained stable across tasks, serving as a baseline to compare the effects of caffeine at different doses. Non-sleep-deprived mice that received caffeine exhibited dose-dependent effects: lower doses (such as 10 and 20 mg/kg) led to improved performance in the novel object recognition test compared to the vehicle control group, while higher doses (such as 80 and 120 mg/kg) resulted in impairments in both spatial memory tasks and the Y maze task. In contrast, in sleep-deprived mice, memory performance declined across all caffeine doses, with higher doses causing more significant impairments in both spatial and non-spatial memory tasks. Based on these results, the researchers suggested that sleep deprivation may alter the cognitive effects of caffeine, adversely impacting memory performance.

Another factor previously found to influence the effect of caffeine upon memory is anxiety levels. For example, in an experimental study by Terry and Phifer (1986), the independent variable was the consumption of caffeine. The researchers manipulated this variable by giving participants either 100 mg of caffeine dissolved in Gatorade or a placebo (Gatorade with a small amount of table salt). This was done through a double-blind procedure, meaning neither the participants nor the researchers knew who was receiving caffeine or the placebo, which helped reduce bias. The dependent variable was memory performance, measured by the participant's ability to recall words from a list. This was assessed using the Auditory Verbal Learning Test (AVLT), where participants were asked to remember and recall a series of words (common nouns) across multiple trials, both immediately and after a delay. The researchers used the number of words recalled to assess memory performance. The results showed that participants who consumed caffeine recalled fewer words compared to those in the control group. The caffeine group particularly struggled with recalling words from the middle-to-end portions of the lists, indicating a negative effect of caffeine on memory retention. Based on these results, the researchers suggested that caffeine, contrary to common belief, may impair memory performance, especially when recalling newly learned information. Anxiety was measured using the neuroticism scale from the Maudsley Personality Inventory and while higher anxiety levels were linked to better recall in the pretest, the combination of anxiety and caffeine worsened memory performance overall. A third factor previously found to influence the effect of caffeine upon memory is aerobic exercise. For example, in an experimental study by Morava et al.

(2019), the researchers recruited twenty-nine non-caffeine consumers and thirty caffeine consumers aged 18-40 and utilized a randomized counterbalanced crossover design across two phases. Participants completed the n-back task to assess working memory after receiving either caffeine or aerobic exercise interventions. The exercise intervention consisted of a single session of moderate-intensity aerobic exercise on a Woodway PPS treadmill, which included a 2-5 minute warm-up walk, 15 minutes of walking at moderate intensity (defined as 40 to 60% of Heart Rate Reserve), and a 2-5 minute cool-down walk. The caffeine administration intervention consisted of oral administration of powdered caffeine. Each participant was given 1.2 mg/kg (body weight) of powdered caffeine dissolved in 100 mL of water. The findings revealed significant improvements in working memory accuracy for caffeine consumers after both caffeine and exercise conditions compared to baseline. Notably, when caffeine and exercise were combined, there were even greater enhancements in accuracy and faster reaction times on the n-back test, suggesting a synergistic effect between the two interventions. Additionally, caffeine withdrawal symptoms, including memory impairments measured through the n-back task, were significantly reduced following caffeine administration after a 12-hour deprivation period. However, this effect was not influenced by anxiety levels or exercise, as neither showed significant interactions with caffeine intake on memory performance. Based on these results, the researchers suggested that in regular consumers caffeine may enhance working memory performance and alleviate memory impairments caused by caffeine withdrawal.

1.3 Hypotheses

Based on the above literature review, we predicted the following hypotheses:

- If sleep decreases then increasing caffeine intake will decrease memory performance.
- If anxiety increases then increasing caffeine intake will decrease memory performance.
- If aerobic exercise increases then increasing caffeine intake will increase memory performance.

2. Methods

2.1 Participants

The two authors of this paper served as the participants in this study. They were both female undergraduate students at Camosun College, completing this study as an assignment for PSYC 245: Drugs & Behaviour Psychology. Both participants were regular caffeine consumers and were grouped together based on a mutual interest in studying caffeine's effects on memory. Their ages ranged from 18-20 years old, with an average age of 19. The first participant had been consuming caffeinated beverages (including coffee, carbonated beverages, and tea) regularly for approximately six years, indicating moderate tolerance as she could drink multiple cups of caffeine without feeling significant effects. The second participant had been a regular consumer of caffeine (primarily tea and coffee) for about five years, also self-reporting moderate tolerance due to her ability to consume similar amounts without noticeable effects. Both participants met the study's inclusion criteria of regular caffeine consumption, which was necessary to assess the potential effects on memory performance found in regular caffeine users by Morava et al. (2019).

2.2 Materials and Procedures

We performed a correlational study to test concurrently all of our hypotheses by examining naturalistic daily changes in their variables longitudinally. Each participant kept a study journal with them at all times over this study's one-week period in order to record self-observations of the following five variables: (1) caffeine intake, (2) sleep, (3) anxiety, (4) aerobic exercise, and (5) memory performance.

2.2.1 Caffeine Intake

Over the course of 14 days, the participants implemented a detailed tracking method to capture day-to-day variations in caffeine intake. Each participant utilized a digital logging application called Barista to accurately record daily caffeine consumption from various sources, including coffee, tea, energy drinks, and caffeinated snacks (see Appendix A for the sample Barista log format). Each entry specified the type and amount consumed, measured in millilitres, grams, and milligrams of caffeine, allowing for precise quantification. This systematic approach provided valuable insights into individual caffeine habits.

2.2.2 Sleep

Over the course of 14 days, participants implemented a detailed tracking method to capture daily variations in sleep. Participants used a dedicated sleep diary to record both objective and subjective sleep data (see Appendix B for the sleep diary template). Each participant documented the time of falling asleep and the time of waking up each night, allowing for precise calculation of total sleep hours. Additionally, each morning, participants rated sleep quality using a five-point scale from one (very poor) to five (excellent). This combination of objective timing and subjective quality ratings provided a comprehensive view of sleep patterns, with numerical scores for both sleep duration and quality captured for each previous night of the study and statistically compared with the values of the other study variables collected during the daytime immediately following each of those nights.

2.2.3 Anxiety

To measure anxiety levels in participants, the State-Trait Anxiety Inventory (STAI) was utilized, available online at ToolOnline.net (see Appendix C for STAI scoring guide). The STAI consisted of 40 items divided into two scales: the State Anxiety scale, which assessed how participants felt at the moment, and the Trait Anxiety scale, which evaluated their general anxiety levels over time. Each participant completed the State Anxiety scale each morning for 14 days, rating their feelings on a four-point Likert scale from one (not at all anxious) to four (very anxious; see Appendix C for details on the Likert scale and scoring guide). This daily assessment captured fluctuations in anxiety levels, allowing for a sensitive measure of how anxiety might impact memory performance. Participants also completed the Trait Anxiety scale once at the beginning of the study to provide a baseline measure of their general anxiety levels. The online platform automatically scored the inventory and provided feedback on each participant's anxiety levels. This comprehensive tracking method ensured sensitivity to daily variations.

2.2.4 Aerobic Exercise

Over the course of 14 days, the participants implemented a detailed tracking method to capture day-to-day variations in aerobic exercise levels. Each participant logged all aerobic exercise activities in a daily exercise journal (see Appendix D for exercise journal template). Each entry detailed the type of exercise performed (e.g., running, cycling, swimming), along with the duration (measured in minutes) and perceived intensity, rated on a scale of one (very light) to five (maximum effort). This approach enabled tracking of both exercise frequency and intensity over the study period, providing insight into potential variations in aerobic activity levels. Each day's overall exercise level was calculated by determining the total duration of exercise completed and averaging the intensity of those exercises. On days when no exercise occurred, intensity values were not recorded.

2.2.5 Memory Performance

To measure memory performance, each participant completed a daily n-back task using the Brain Workshop software (see Appendix E for n-back task setup and instructions). The task, administered on a computer, was designed to assess working memory by prompting participants to recall sequences of visual or auditory stimuli presented in intervals (e.g., two-back or three-back). Each session lasted approximately five minutes and automatically recorded response accuracy (percentage of correct responses) and response time for each trial. Data was saved in a digital format, capturing both response accuracy and latency, ensuring detailed tracking of memory outcomes. Participants completed the task daily for a minimum of 14 days, typically in the evening after recording that day's other variable measurements. This timing allowed for potential influences from those variables, such as caffeine intake, anxiety levels, and exercise, to be reflected in the memory performance data.

2.3 Planned Analyses

In this study, statistical analyses were performed using Microsoft Excel (version 2024) to evaluate the data. To assess the strength and statistical significance of associations that memory has with caffeine intake, sleep, anxiety, and exercise, we performed Pearson product-moment correlations of accuracy scores on the n-back task with mg of caffeine consumed, hours of sleep attained, subjective sleep quality scores, STAI scores, minutes of exercise attained, and subjective exercise intensity scores. We performed all of the above correlations separately for each participant as well as using data pooled across all of the participants. To assess the moderating influence of the other variables predicted by our three hypotheses, we performed multiple regression analyses of their predictor variable (caffeine intake), their potential moderating variable (sleep, anxiety, or aerobic exercise), an interaction term (creating by multiplying the values of the predictor variable and the potential moderating variable for each day), and their outcome variable (memory performance). For testing Hypothesis #1 that sleep duration moderates the relationship between caffeine and memory, we examined the regression output to see if the interaction term created with values of mg of caffeine consumed multiplied by either hours of sleep attained or subjective sleep quality scores was statistically significant. For testing Hypothesis #2 that anxiety moderates the relationship between caffeine and memory, we examined the regression output to see if the interaction term created with values of mg of caffeine consumed multiplied by STAI scores was statistically significant. For testing Hypothesis #3 that exercise moderates the relationship between caffeine and memory, we examined the regression output to see if the interaction term created with values of mg of caffeine consumed multiplied by either minutes of exercise attained or subjective exercise intensity scores was statistically significant. For the correlation and regression analyses using pooled data, in addition to using the raw data, we also performed analyses after we had first transformed the data from each participant into *z*-scores in order to standardize differences in averages and variability seen between the participants in their data and thus make them more comparable. A coefficient was considered statistically significant if the probability of its random occurrence (*p*) was < .05 (i.e., less than 5% of the time expected by chance alone).

3. Results

3.1 Correlational Analyses

The correlational analyses revealed no significant relationships between memory performance and caffeine intake but did find memory performance was significantly correlated with measures of sleep, anxiety, and exercise (see Table 1). Caffeine intake was not significantly correlated with memory performance in either of the two participants' data (*r* = -.36 & .42, *p* = .21 & .14), the pooled raw data (*r* = .15, *p* = .46, see Figure 1), or the pooled standardized data (*r* = .03, *p* = .87, see Figure 2). Sleep duration was significantly correlated with memory performance in one of the two participants' data (*r* = .13 & .78, *p* = .68 & .0005), the pooled raw data (*r* = .47, *p* = .01, see Figure 3), and the pooled standardized data (*r* = .45, *p* = .01, see Figure 4). Sleep quality was significantly correlated with memory performance in one of the two participants' data (*r* = -.16 & .90, *p* = .59 & .0000007) and the pooled raw data (*r* = .38, *p* = .04, see Figure 5), but not in the pooled standardized data (*r* = .37, *p* = .05, see Figure 6). Anxiety was significantly correlated with memory performance in both of the two participants' data (*r* = -.57 & -.70, *p* = .03 & .004), the pooled raw data (*r* = -0.57, *p* = .001, see Figure 7), and the pooled standardized data (*r* = -.64, *p* = .0002, see Figure 8). Exercise duration was not significantly correlated with memory performance in either of the two participants' data (*r* = .12 & .24, *p* = .70 & .41), the pooled raw data (*r* = .10, *p* = .60, see Figure 9), or the pooled standardized data (*r* = .18, *p* = .36, see Figure 10). Exercise intensity was not significantly correlated with memory performance in either of the two participants' data (*r* = -.47 & -.35, *p* = .09 & .30) or the pooled raw data (*r* = -.37, *p* = .07, see Figure 11), but was significantly correlated in the pooled standardized data (*r* = -.42, *p* = .04, see Figure 12). Since no exercise was performed on three of the study days for one of the participants, the above correlations of exercise intensity included a total of just 25 days of pooled data instead of the full 28 days (four-weeks) of pooled data included in the other correlations. In a comparison of all the correlation coefficients when using the pooled standardized data for their analyses, the variable that showed the strongest correlation with memory performance was anxiety with an *r*-value of -.64, indicating a large effect size ($r \geq 0.50$).

3.2 Multiple Regression Analyses

The multiple regression analyses revealed that the relationship between caffeine intake and memory performance was not significantly moderated by any of the study variables except for sleep duration (see Table 2). The interaction of caffeine with sleep duration did not significantly predict memory performance in the pooled raw data (t = -.22, p = .83; see Figure 13) but did in the pooled standardized data (t = -2.10, p = .046; see Figure 14). Visual inspection of the pooled standardized data in Figure 14 showed that memory performance displayed a positive relationship with caffeine intake when sleep duration was at levels below average (sleep duration z-scores < 0), close to no relationship with caffeine intake when sleep duration was at low-to-moderate levels above average (sleep duration z-scores = 0 to 1), and a negative relationship with caffeine intake when sleep duration was at high levels above average (sleep duration z-scores > 1). Conversely, by treating sleep duration as the predictor variable and caffeine intake as the moderator variable (see Figure 15), this same pooled standardized data can be interpreted as showing that memory performance displayed a positive relationship with sleep duration when caffeine intake was at levels below average amounts (caffeine intake z-scores < 0), close to no relationship with sleep duration when caffeine intake was at low-to-moderate levels above average (caffeine intake z-scores = 0 to 0.75), and a negative relationship with sleep duration when caffeine intake was at high levels above average (caffeine intake z-scores > 0.75). The significant interaction between caffeine intake and sleep duration upon memory performance occurred despite no significant correlation found directly between sleep duration and caffeine intake in either of the two participants' data (r = -.39 & .25, p = .17 & .40), the pooled raw data (r = .22, p = .26, see Figure 16), or the pooled standardized data (r = -.07, p = .73, see Figure 17). In contrast to the significant interaction of caffeine intake with sleep duration, the interaction of caffeine intake with all of the other study variables did not significantly predict memory performance in either the pooled raw data (all absolute $t \leq$ .94, all $p \geq$ .36) or the pooled standardized data (all absolute t ≤ 1.96, all $p \geq$ .06).

4. Discussion

4.1 Summary of Results

Based on previous research, we hypothesized that changes in three variables would moderate the relationship between caffeine and memory performance: lower sleep durations would predict increases in caffeine intake being associated with decreases in memory performance (Hypothesis #1), higher anxiety levels would predict increases in caffeine intake being associated with decreases in memory performance (Hypothesis #2), and higher levels of aerobic exercise would predict increases in caffeine intake being associated with increases in memory performance (Hypothesis #3). While data pooled and standardized across participants in our study did show that caffeine intake had a significant interaction with sleep duration (p < 0.05) and a trend towards a significant interaction with sleep quality (p = 0.06) upon memory performance, these findings were in the opposite direction from what we predicted, with improved instead of impaired memory performance being associated with above average caffeine intake levels when sleep durations were below average. Anxiety and exercise failed to show any significant interactions with caffeine intake upon memory performance. These results indicate that none of our hypotheses were supported by our data.

4.2 Relation of Results to Past Research

The findings in our study, which revealed that when sleep duration is low then increased caffeine intake is associated with increased memory performance, differed from previous research done by Onaolapo et al. (2015). Their research demonstrated significant impairments in memory due to the combined effects of sleep deprivation and caffeine in mice (Onaolapo et al., 2015). Onaolapo et al. (2015) employed an experimental research design to detect the detrimental effects of caffeine. While our correlational research design was not able to similarly establish whether any relationships between variables were causal ones, it should still have been sufficiently sensitive to detect the existence and direction of any relationships in general, independent of whether they are causal or non-causal ones. In our research, the pattern of interaction found between sleep duration and caffeine intake upon memory performance suggests that unlike the results of experiments done with mice, increased caffeine intake when sleep is disturbed does not impair memory performance in human participants under naturalistic conditions. The methodological variations —such as species differences, measurement tools, and environmental contexts—likely affected the difference in our findings compared to past research (Onaolapo et al., 2015). To test whether increased caffeine intake actually causes enhanced memory performance when sleep duration was low, future studies should adopt an experimental design in human participants. Additionally, longitudinal designs could explore whether chronic caffeine use interacts with habitual sleep patterns to impact memory differently from the acute conditions explored in the current study. These refinements could clarify the conditions under which caffeine and sleep disturbances affect memory.

Our findings differed from those of Terry and Phifer (1986) who observed a negative relationship between anxiety levels and caffeine's impact on memory performance. In their experimental study, higher anxiety levels combined with caffeine consumption were associated with worsened memory recall, particularly for information learned later in a sequence (Terry & Phifer, 1986). However, in our study, while we observed a large negative correlation between anxiety and memory performance, caffeine intake did not significantly moderate this relationship or show a significant correlation directly with memory performance. Our study measured anxiety using the State-Trait Anxiety Inventory (STAI), a standardized and widely used tool, similar to the neuroticism scale used in the Terry and Phifer (1986) study. The lack of significant findings in our study may be attributed to our reliance on naturalistic caffeine consumption, which lacked the controlled dose manipulation present in Terry and Phifer’s work (Terry & Phifer, 1986). In their study, participants received standardized caffeine doses, ensuring consistent intake levels across individuals. In contrast, our participants consumed varying amounts of caffeine based on their typical daily habits, which may have introduced inconsistencies in dosage. These variations could have reduced the likelihood of detecting significant effects, particularly if some participants consumed doses too low to influence memory performance. Additionally, the range of caffeine doses in our study may have differed from those tested by Terry and Phifer, further contributing to the lack of significant results. Additionally, while we used the n-back task to measure working memory performance, Terry and Phifer employed the Auditory

Verbal Learning Test (AVLT), which focuses on verbal recall (Terry & Phifer, 1986). These methodological differences might explain the discrepancies between our findings and theirs. Future research should combine the controlled dosing approach with diverse memory assessments to better explore the interaction between anxiety, caffeine, and various types of memory performance. The findings in our research which, although showing a significant correlation between exercise intensity and memory performance in the pooled standardized data, failed to show a significant interaction between caffeine intake and exercise upon memory performance, contrast with earlier research done by Morava et al. (2019). Their study demonstrated synergistic enhancements in working memory accuracy and reaction times when caffeine consumption was combined with aerobic exercise. Morava et al. (2019) observed significant improvements in cognitive performance, such as faster reaction times and greater accuracy on the n-back test, under controlled conditions. The differences in findings might stem from methodological variations between the two studies. Terry and Phifer (1986) conducted a controlled experimental study, systematically manipulating caffeine and exercise variables and focusing on immediate cognitive outcomes. This controlled design ensured precise dosage administration and timing, reducing variability and enhancing the detection of potential synergistic effects (Morava et al., 2019). In contrast, our observational study relied on self-reported data for caffeine intake and exercise, which introduces variability and potential inaccuracies. Participants may have misestimated their caffeine intake, particularly if they consumed beverages with unclear labeling or variable caffeine content. Similarly, self-reported exercise data may have been imprecise, especially regarding intensity levels. These inaccuracies, combined with natural fluctuations in participants' daily habits, may have reduced our study's sensitivity to detect subtle or complex interactions. Furthermore, the Morava et al. (2019) investigation included participants experiencing withdrawal symptoms, which may have amplified the observed effects of caffeine. This context-dependent influence was not accounted for in our study, potentially contributing to the discrepancy. Future studies could explore the role of withdrawal symptoms, caffeine tolerance, and the timing of exercise relative to caffeine consumption to better understand the context-dependent effects. Longitudinal studies could also examine whether habitual patterns of exercise and caffeine intake interact over time to influence memory performance.

4.3 Implications of Results

Our findings suggest that anxiety and exercise did not significantly influence the relationship between caffeine intake and memory performance. This indicates that students seeking to optimize their cognitive performance through caffeine use may not need to rely on strategies like exercise to counteract potential negative effects. Instead, maintaining consistent caffeine consumption habits and being mindful of individual responses may be more effective. These insights can help students make informed decisions about their caffeine intake when managing academic demands, focus, and cognitive well-being.

Our research aimed to explore the factors that determine whether caffeine impacts memory performance, particularly the roles of sleep, anxiety, and exercise. We hoped this knowledge would provide practical guidance for students looking to enhance focus and cognitive performance. While our findings did not support our hypotheses, they suggest that caffeine’s effects on memory may be less dependent on anxiety and exercise than previously thought. This outcome emphasizes the need for further research to better understand the conditions under which caffeine consumption influences memory.

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Table 1

Correlational Analyses of Study Variables

Study Variables	Participant #1		Participant #2		Pooled raw data		Pooled standardized data	
	r	*n*	*r*	*n*	*r*	*n*	*r*	*n*
Caffeine intake & memory performance	-0.36	14	0.42	14	0.15	28	0.03	28
Sleep duration & memory performance	0.13	14	0.78*	14	0.47*	28	0.45*	28
Sleep quality & memory performance	-0.16	14	0.90*	14	0.38*	28	0.37	28
Anxiety & memory performance	-0.57*	14	-0.70*	14	-0.57*	28	-0.64*	28
Exercise duration & memory performance	0.12	14	0.24	14	0.10	28	0.18	28
Exercise intensity & memory performance	-0.47	14	-0.35	11	-0.37	25	-0.42*	25

* $p < .05$.

Table 2

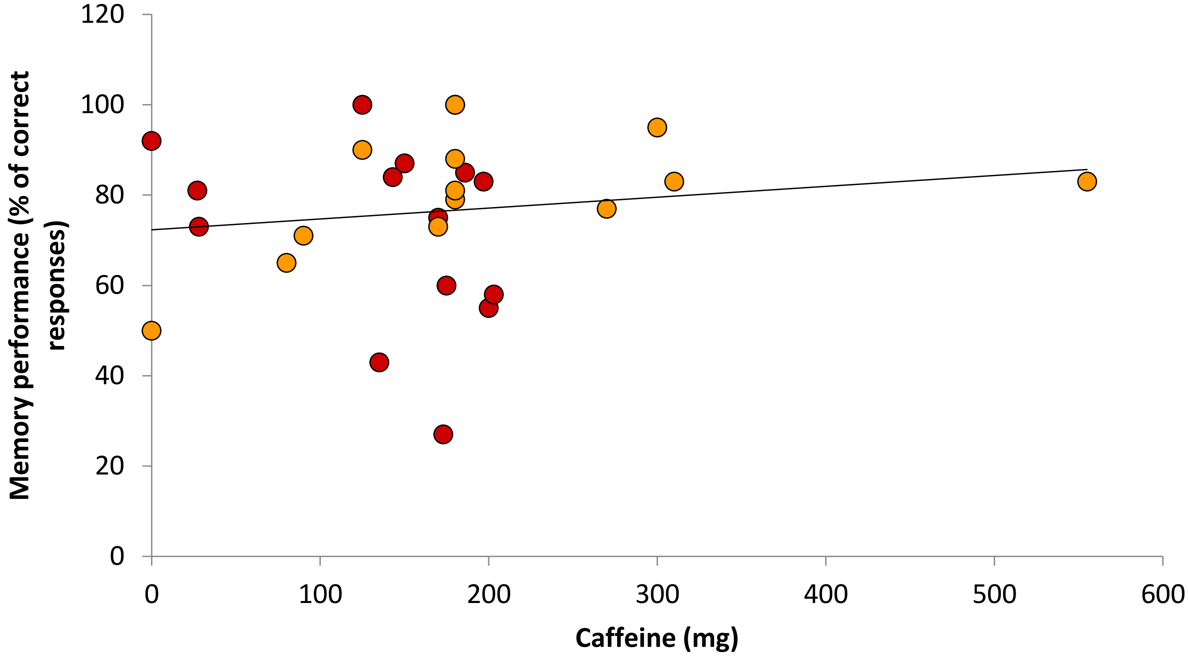
Multiple Regression Analyses of Interaction Terms for Caffeine Intake with Study Variables on Memory Performance Using Either Raw or Standardized (z-Scores) Pooled Data

Interaction Term	*df*		*t*-Statistic		*p*-Value	
	Raw	*z*-Score	Raw	*z*-Score	Raw	*z*-Score
Caffeine intake * sleep duration	24	24	-0.22	-2.10	0.83	0.046
Caffeine intake * sleep quality	24	24	0.11	-1.96	0.91	0.06
Caffeine intake * anxiety	24	24	-0.36	0.17	0.72	0.87
Caffeine intake * exercise duration	24	24	-0.94	-1.10	0.36	0.28
Caffeine intake * exercise intensity	21	21	-0.55	-0.90	0.59	0.38

Note. *df* = the residual degrees of freedom which was calculated by the total number of observations (25 or 28 days) minus the number of predictors (3 including the interaction term) minus one, *t*-statistic = the ratio of the difference in a number's known value from its expected value over the standard error of the distribution it was derived from, *p*-value = the probability (expressed as a proportion) that a given set of data occurred by chance alone, and *z*-score = the number of standard deviations away that a value is from the mean of the distribution it was derived from. $p < .05$ indicates statistical significance.

Figure 1

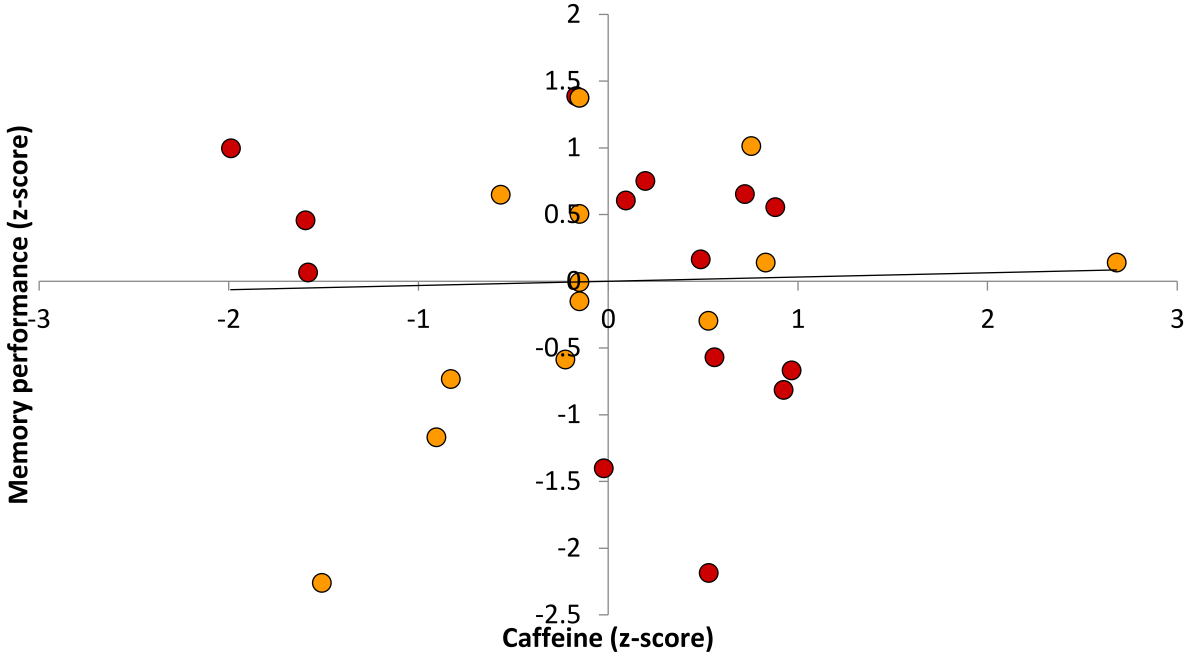
Association Between Caffeine Intake and Memory Performance Using Pooled Raw Data



Notes. Marker colour differentiates participants: red = participant #1 and orange = participant #2. Some data might not be visible in the figure due to overlapping markers.

Figure 2

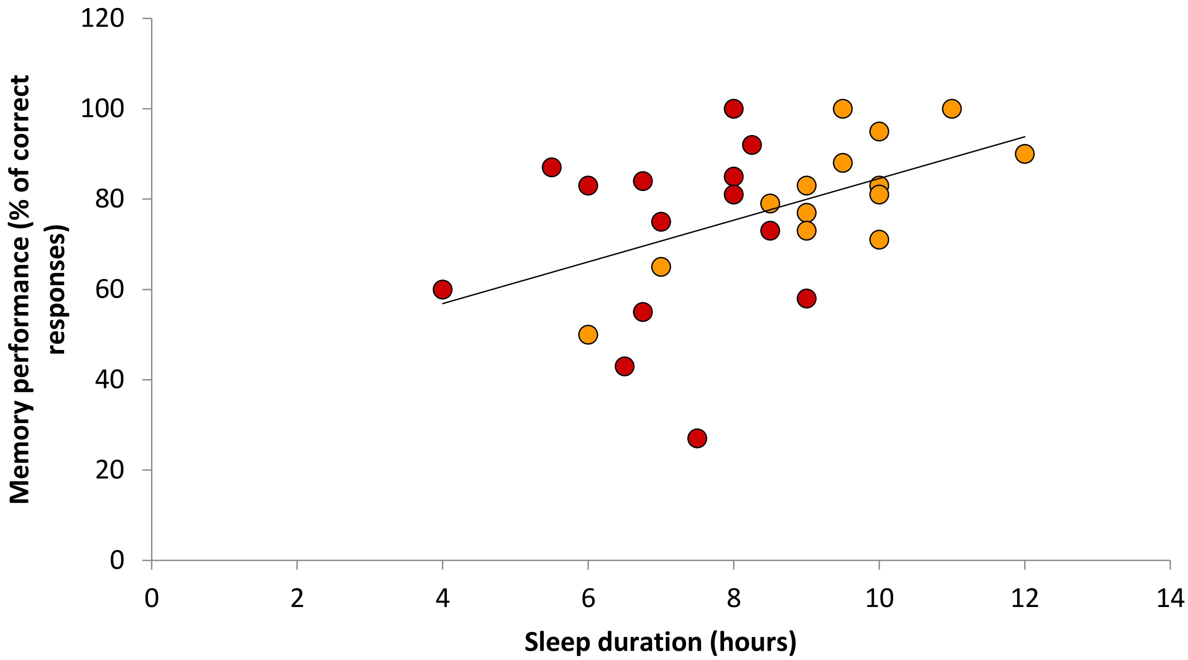
Association Between Caffeine Intake and Memory Performance Using Pooled Standardized Data



Notes. Marker colour differentiates participants: red = participant #1 and orange = participant #2. Some data might not be visible in the figure due to overlapping markers.

Figure 3

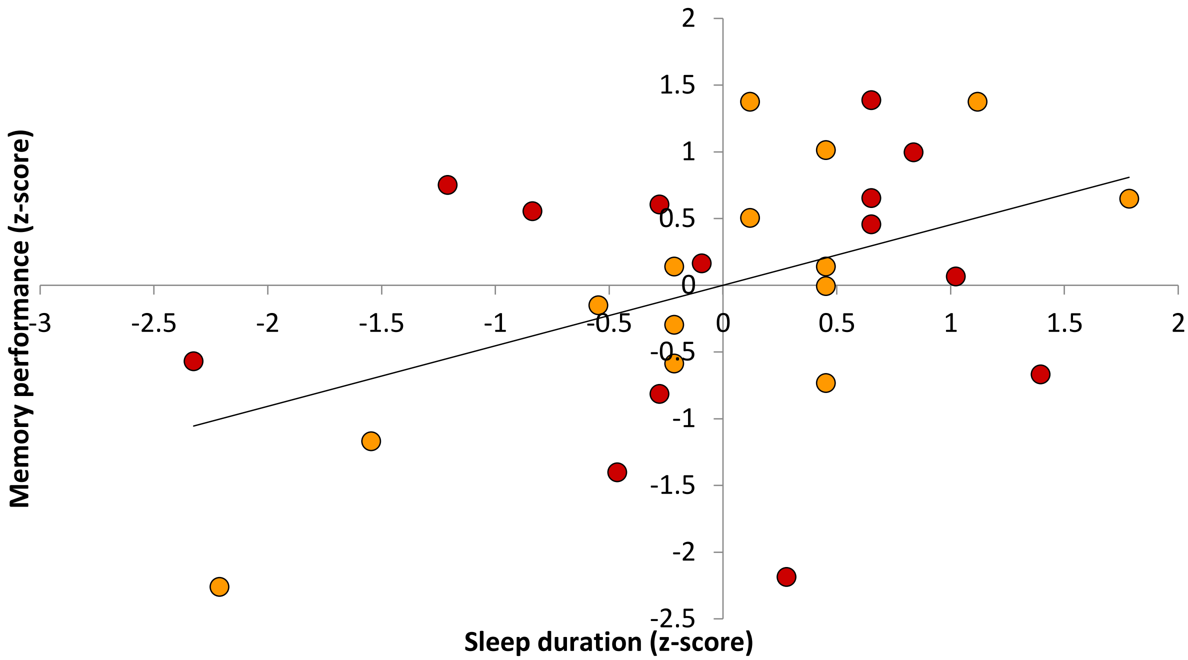
Association Between Sleep Duration and Memory Performance Using Pooled Raw Data



Notes. Marker colour differentiates participants: red = participant #1 and orange = participant #2. Some data might not be visible in the figure due to overlapping markers.

Figure 4

Association Between Sleep Duration and Memory Performance Using Pooled Standardized Data

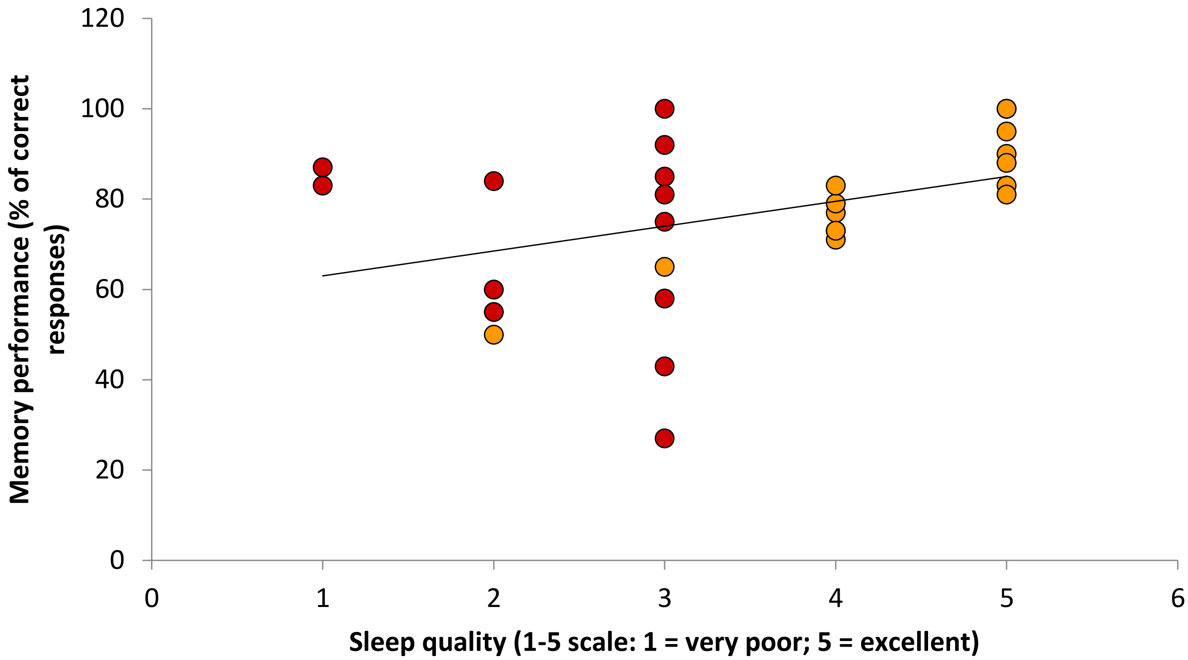


Notes. Marker colour differentiates participants: red = participant #1 orange = participant #2.

Some data might not be visible in the figure due to overlapping markers.

Figure 5

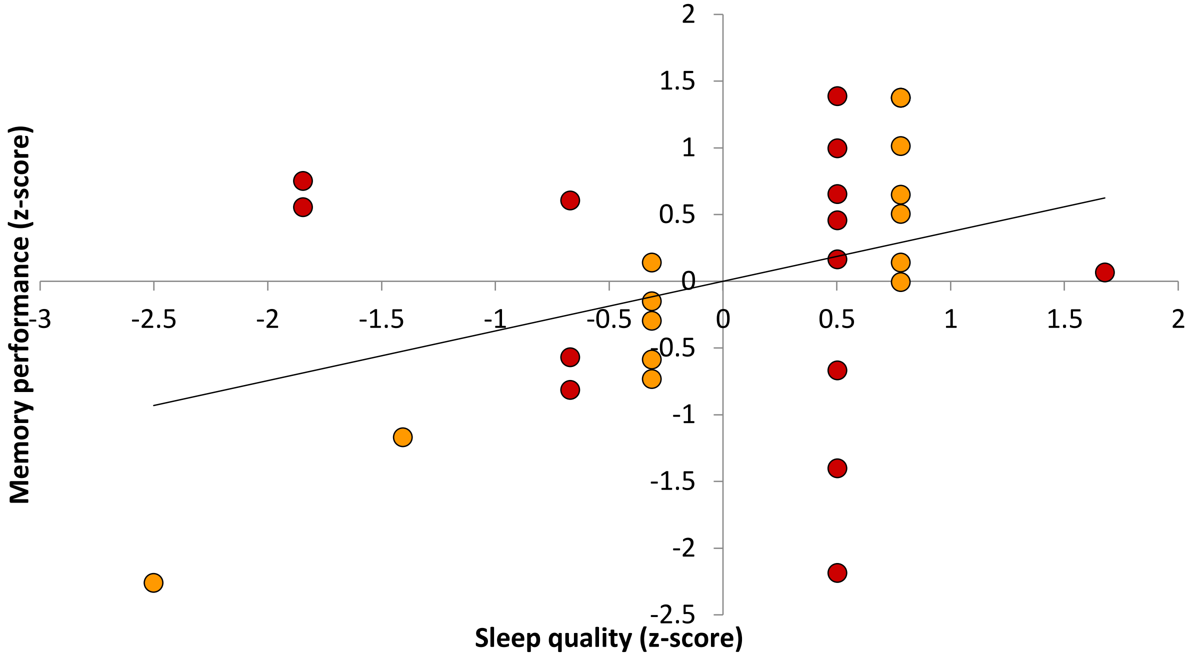
Association Between Sleep Quality and Memory Performance Using Pooled Raw Data



Notes. Marker colour differentiates participants: red = participant #1 and orange = participant #2. Some data might not be visible in the figure due to overlapping markers.

Figure 6

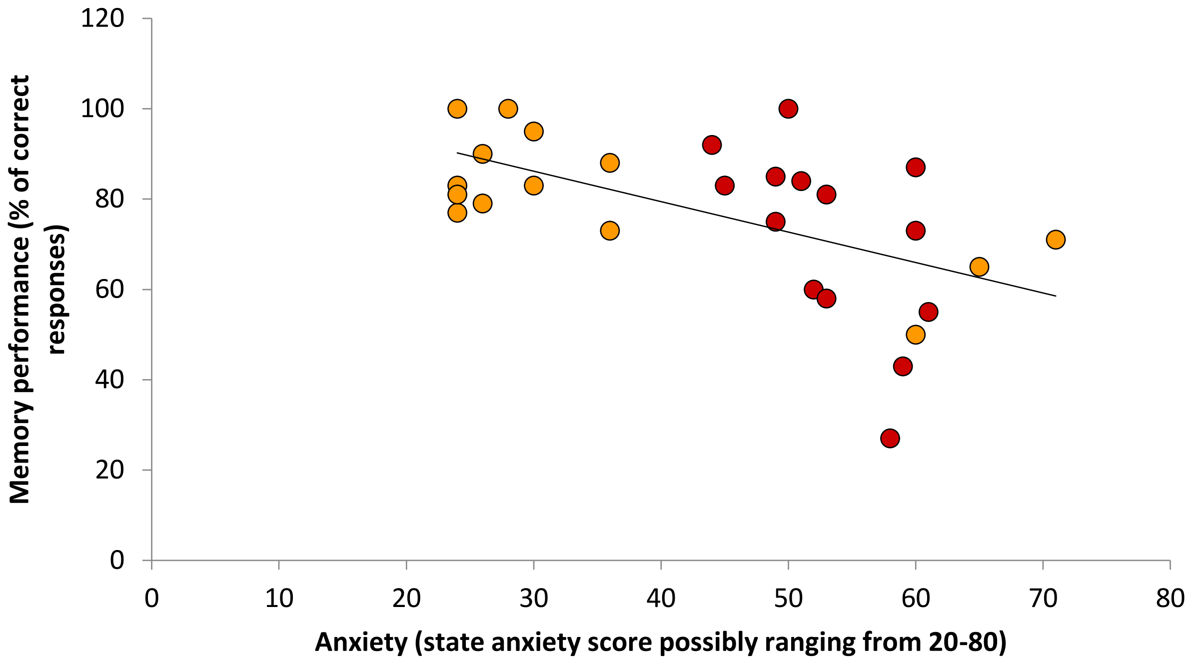
Association Between Sleep Quality and Memory Performance Using Pooled Standardized Data



Notes. Marker colour differentiates participants: red = participant #1 and orange = participant #2. Some data might not be visible in the figure due to overlapping markers.

Figure 7

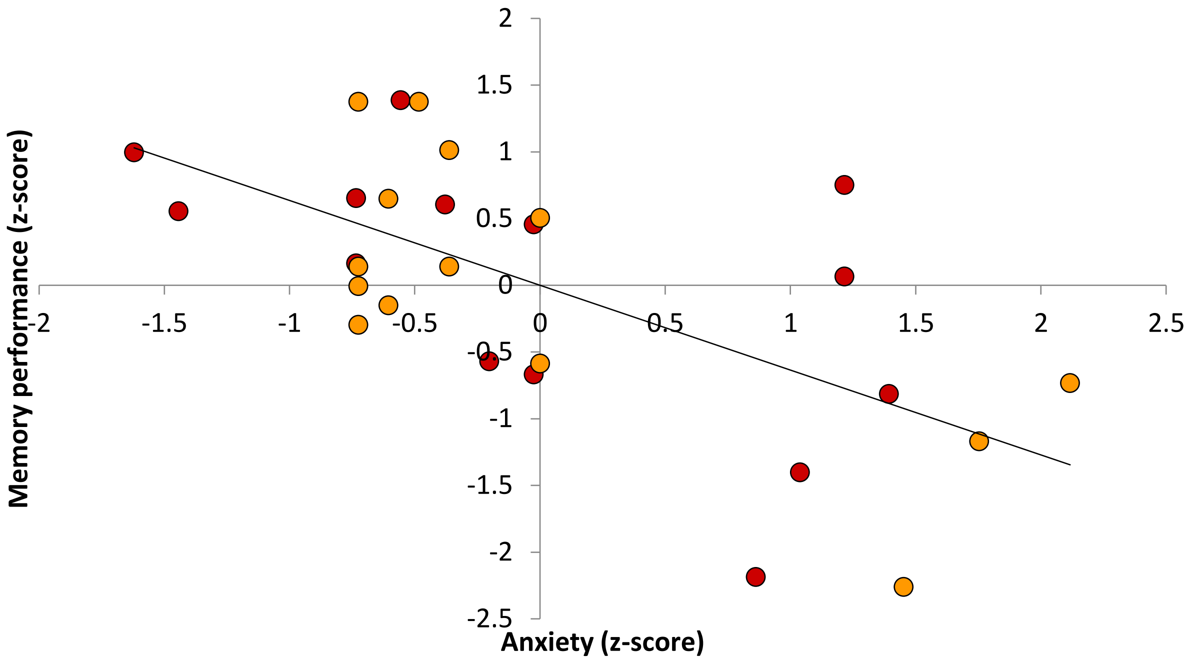
Association Between Anxiety and Memory Performance Using Pooled Raw Data



Notes. Marker colour differentiates participants: red = participant #1 and orange = participant #2. Some data might not be visible in the figure due to overlapping markers.

Figure 8

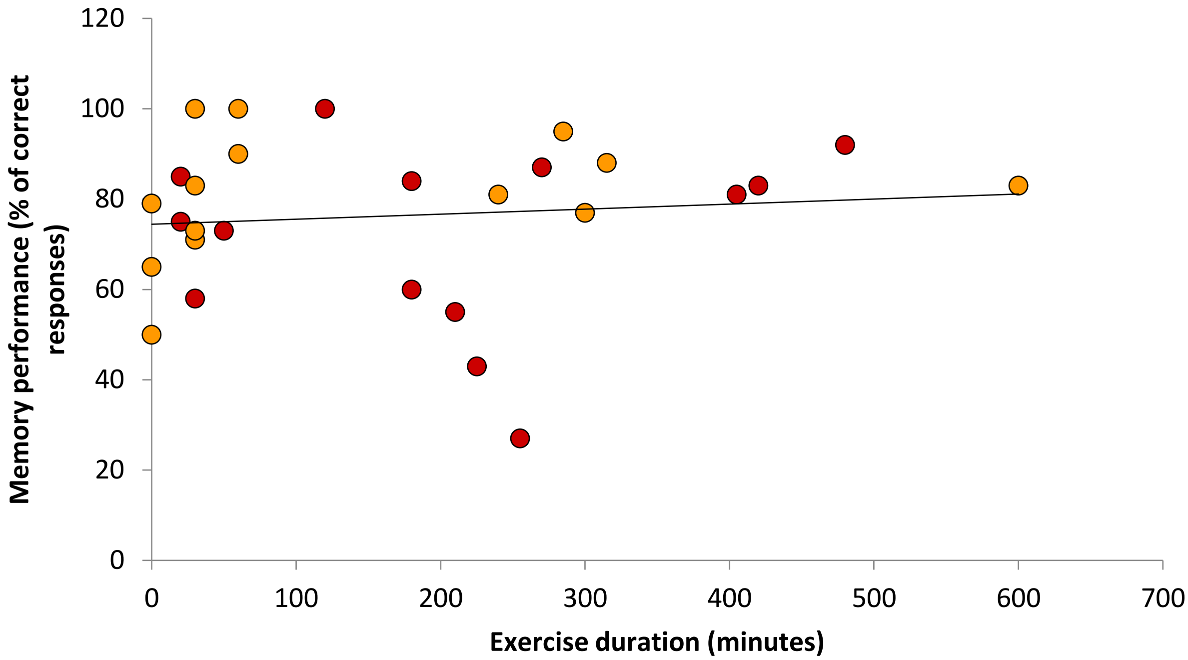
Association Between Anxiety and Memory Performance Using Pooled Standardized Data



Notes. Marker colour differentiates participants: red = participant #1 and orange = participant #2. Some data might not be visible in the figure due to overlapping markers.

Figure 9

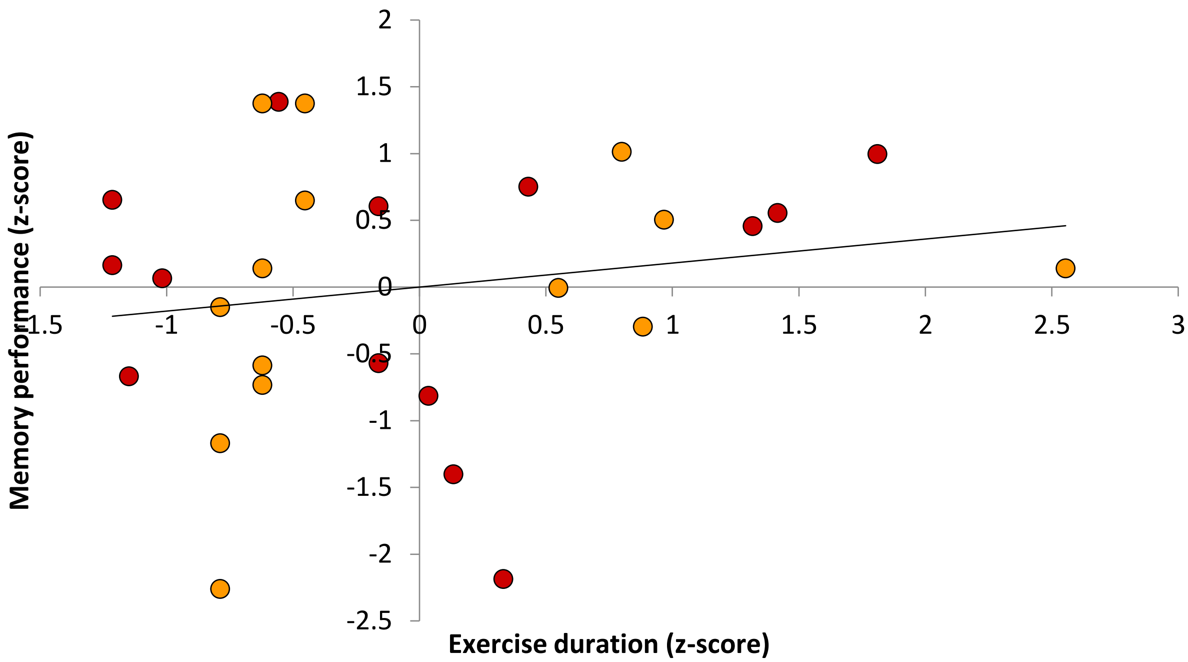
Association Between Exercise Duration and Memory Performance Using Pooled Raw Data



Notes. Marker colour differentiates participants: red = participant #1 and orange = participant #2. Some data might not be visible in the figure due to overlapping markers.

Figure 10

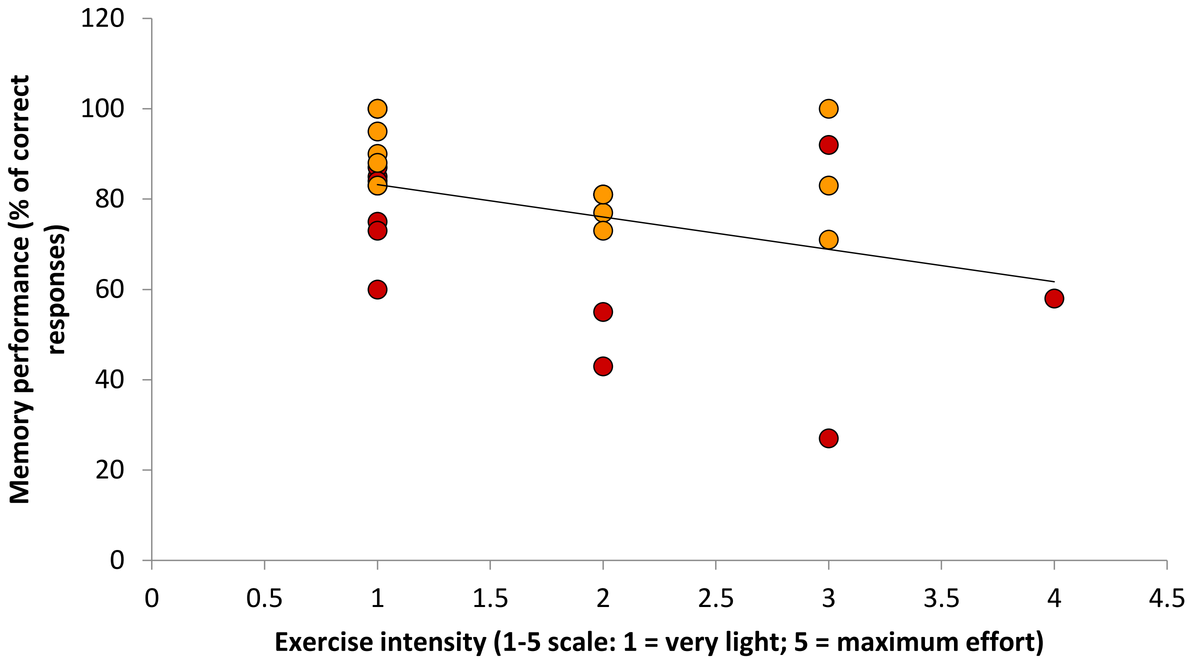
Association Between Exercise Duration and Memory Performance Using Pooled Standardized Data



Notes. Marker colour differentiates participants: red = participant #1 and orange = participant #2. Some data might not be visible in the figure due to overlapping markers.

Figure 11

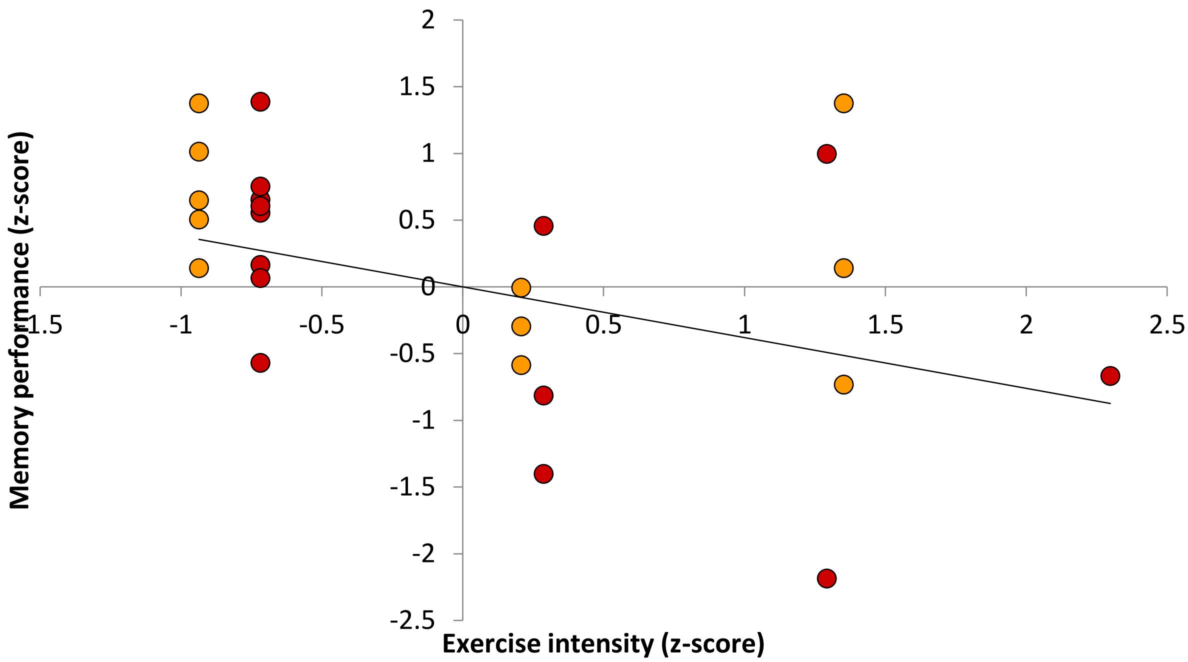
Association Between Exercise Intensity and Memory Performance Using Pooled Raw Data



Notes. Marker colour differentiates participants: red = participant #1 and orange = participant #2. Some data might not be visible in the figure due to overlapping markers.

Figure 12

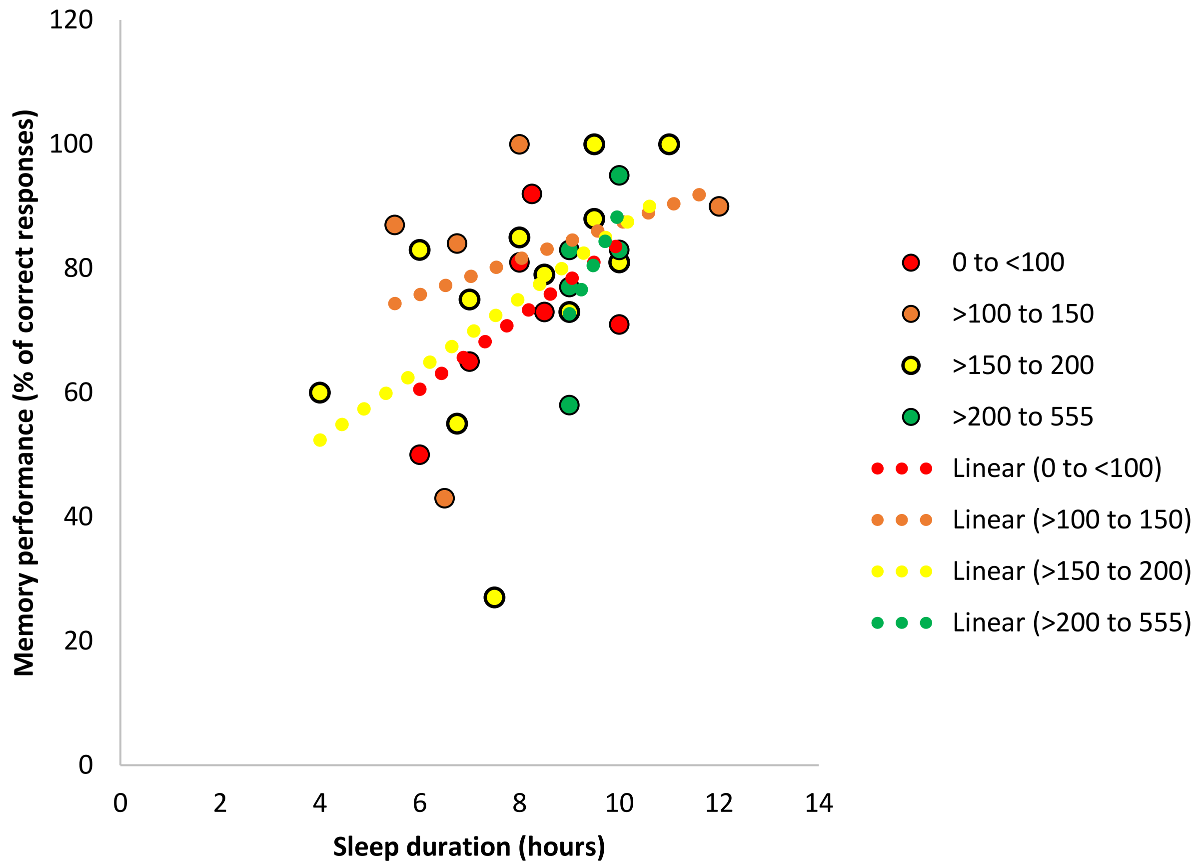
Association Between Exercise Intensity and Memory Performance Using Pooled Standardized Data



Notes. Marker colour differentiates participants: red = participant #1 and orange = participant #2. Some data might not be visible in the figure due to overlapping markers.

Figure 13

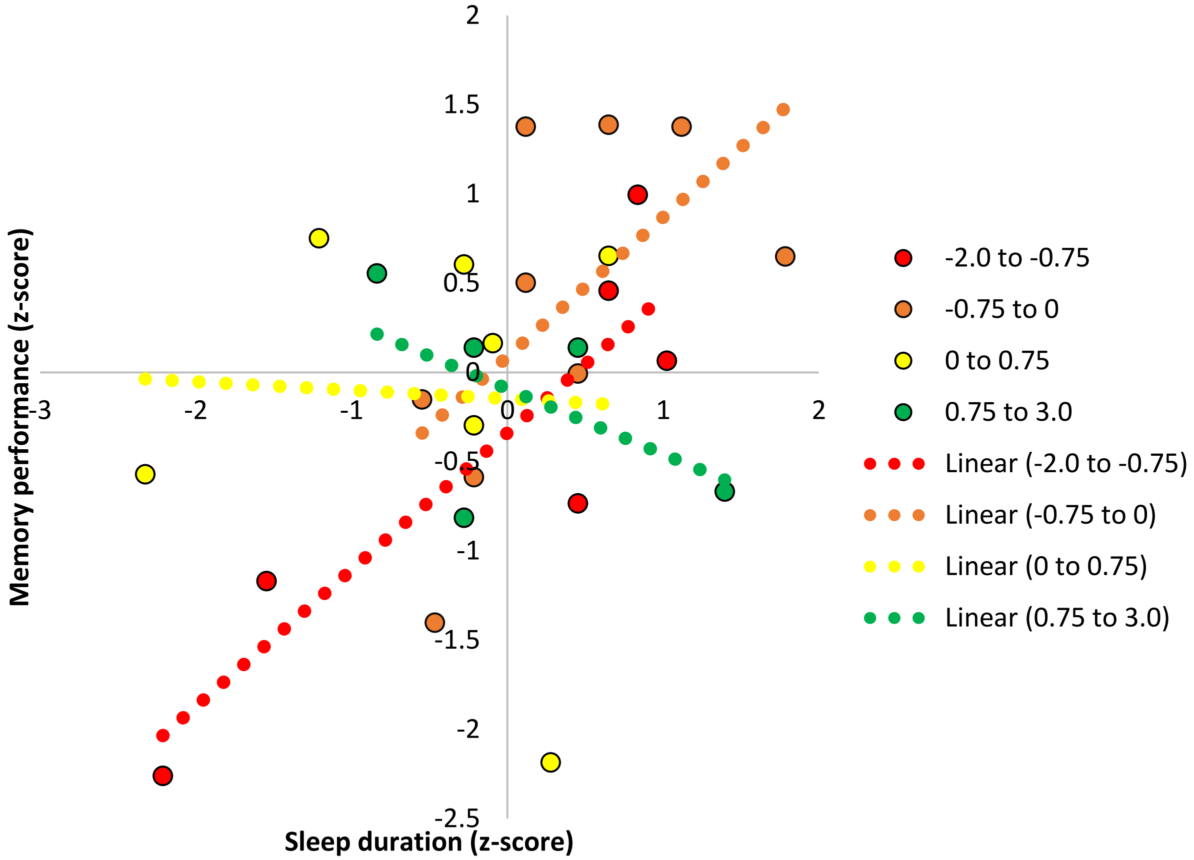
Association Between Sleep Duration and Memory Performance for Different Caffeine Intake Levels Using Pooled Raw Data



Notes. Marker colour differentiates caffeine intake: red = 0 to <100 mg, orange = >100 to 150 mg, yellow = >150 to 200 mg, and green = >200 to 555 mg. Some data might not be visible in the figure due to overlapping markers.

Figure 14

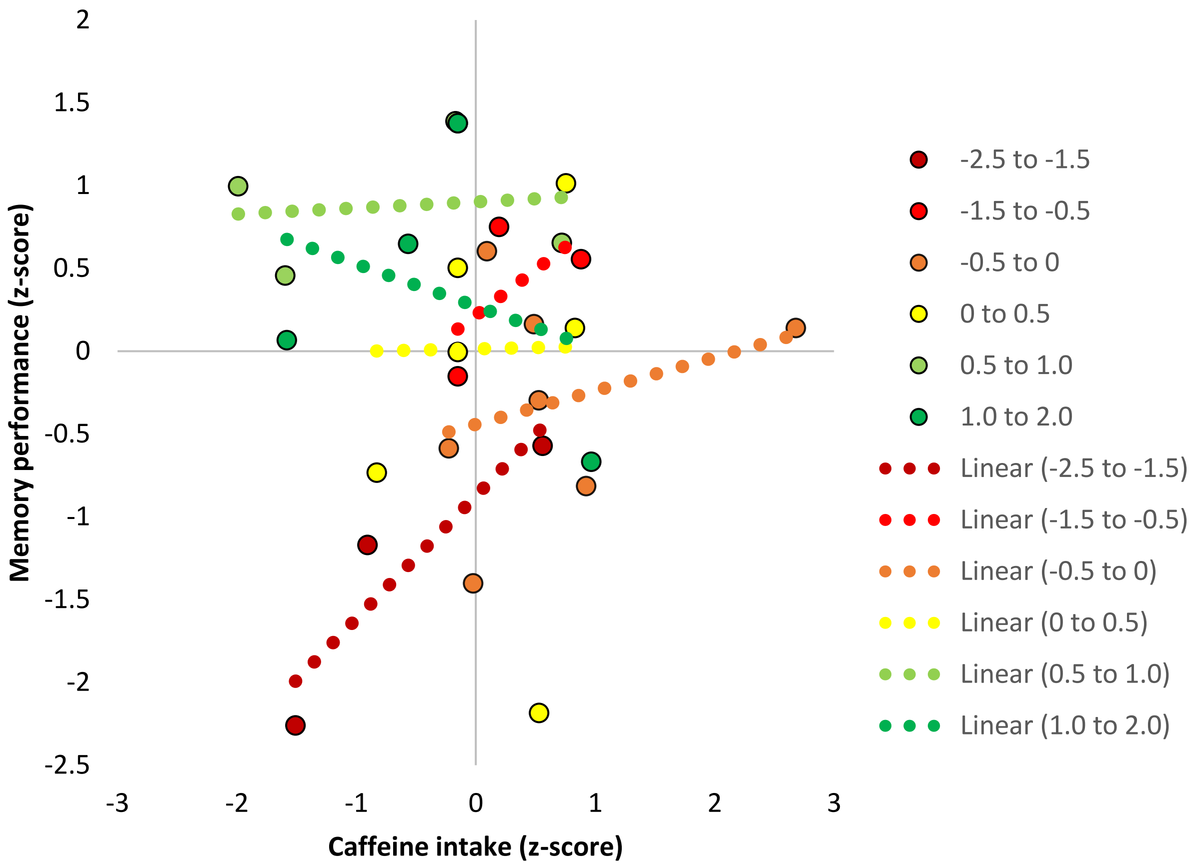
Association Between Sleep Duration and Memory Performance for Different Caffeine Intake Levels Using Pooled Standardized Data



Notes. Marker colour differentiates caffeine intake: red = -2.0 to -0.75 *z*, orange = -0.75 to 0 *z*, yellow = 0 to 0.75 *z*, and green = 0.75 to 3.0 *z*. Some data might not be visible in the figure due to overlapping markers.

Figure 15

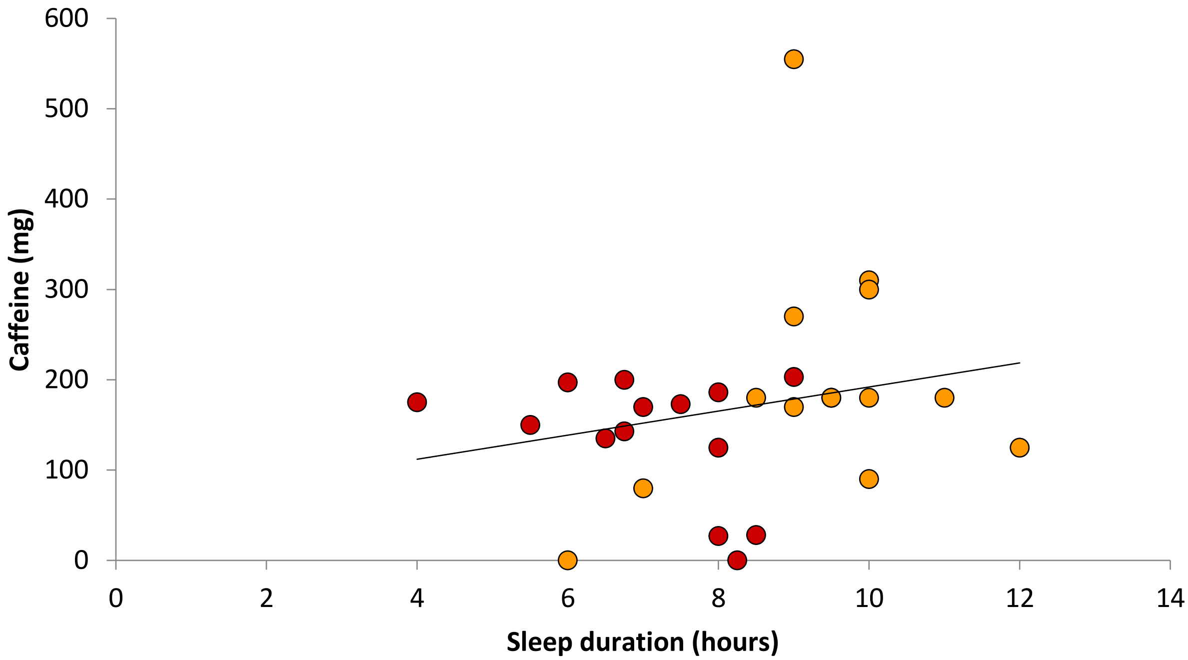
Association Between Caffeine Intake and Memory Performance for Different Sleep Duration Amounts Using Pooled Standardized Data



Notes. Marker colour differentiates sleep duration: dark red = -2.5 to -1.5 *z*, light red = -1.5 to -0.5 *z*, orange = -0.5 to 0 *z*, yellow = 0 to 0.5 *z*, light green = 0.5 to 1.0 *z*, and dark green = 1.0 to 2.0 *z*. Some data might not be visible in the figure due to overlapping markers.

Figure 16

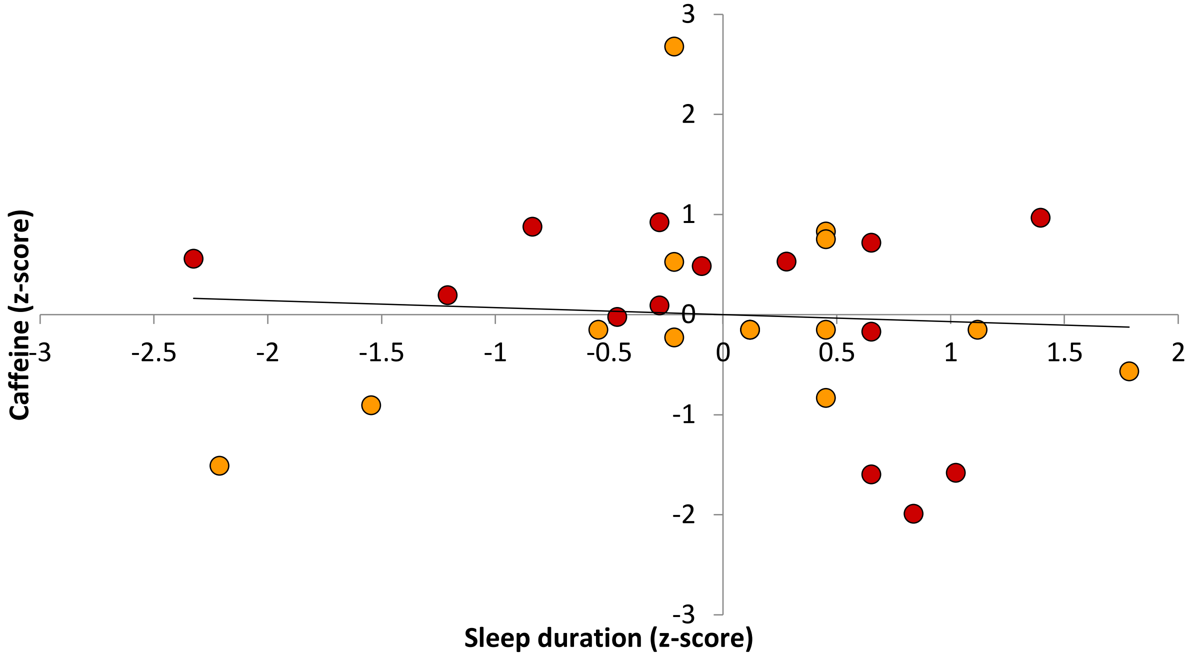
Association Between Sleep Duration and Caffeine Intake Using Pooled Raw Data



Notes. Marker colour differentiates participants: red = participant #1 and orange = participant #2. Some data might not be visible in the figure due to overlapping markers.

Figure 17

Association Between Sleep Duration and Caffeine Intake Using Pooled Standardized Data



Notes. Marker colour differentiates participants: red = participant #1 and orange = participant #2. Some data might not be visible in the figure due to overlapping markers.

Appendix A: Sample Barista Log Format for Caffeine Intake Tracking

Date	**Time**	**Beverage/ Food Item**	**Source**	**Amount (mL or grams)**	**Caffeine Content (mg)**	**Notes**
2024-10-01	8:00 AM	Coffee	Brewed, dark roast	240 mL	95 mg	Home-brewed
2024-10-01	11:30 AM	Tea	Black tea	200 mL	47 mg	Cafe-purchased
2024-10-01	2:00 PM	Energy drink	Red Bull	250 mL	80 mg	Store-bought
2024-10-01	5:15 PM	Chocolate bar	Dark chocolate	50 g	20 mg	Estimated from CNF (Canadian Nutrient File)
2024-10-01	-	Daily Total	-	-	245 mg	

Note: Participants should note if caffeine content was estimated from the Canadian Nutrient File (CNF) or other nutritional information sources.

Appendix B: Sleep Diary Template

Participant Name: ______________________

Date: ______________________

Sleep Entry

1. Time went to bed: ______________________
2. Time fell asleep: ______________________
3. Time woke up: ______________________
4. Total sleep duration (in hours): ______________________

5. Sleep quality rating (1-5): ______________________

   (1 = Very Poor, 2 = Poor, 3 = Fair, 4 = Good, 5 = Excellent)

6. Notes/Comments:

   - ______________________
   - ______________________

Reminder: Please record times consistently in either 24-hour format or AM/PM format.

Appendix C: Scoring Guide for State-Trait Anxiety Inventory (STAI)

Scale	**Item**	**Description**	**Score**	**Interpretation Guide**
	Numbers		**Range**	
State	Items	Measures current feelings of anxiety or calmness, reflecting the participant's anxiety “state” at a given moment.	20-80	Scores are categorized as low (20-39), moderate (40-59), or high (60-80) levels of state anxiety.
Anxiety	1-20			
Trait	Items	Assesses general and enduring anxiety characteristics, indicating a baseline level of anxiety "trait."	20-80	Scores are categorized as low (20-39), moderate (40-59), or high (60-80) levels of trait anxiety.
Anxiety	21-40			

Scoring and Likert Scale Details:

- Likert Scale for STAI: Each item is rated on a four-point Likert scale as follows:
    - 1 - Not at all anxious
    - 2 - Somewhat anxious
    - 3 - Moderately anxious
    - 4 - Very anxious

Note: Lower scores indicate less anxiety, while higher scores indicate greater anxiety for both State and Trait scales.

- Daily State Anxiety Scores: Participants completed the State Anxiety scale each morning for seven days to capture day-to-day fluctuations in anxiety.
- Trait Anxiety Baseline Score: The Trait Anxiety scale was administered once at the beginning of the study to establish a baseline of each participant's general anxiety.
- Automatic Scoring: ToolOnline.net automatically scored each inventory and categorized scores into low, moderate, or high anxiety levels based on the participant's responses.

Appendix D: Exercise Journal Template

Participant Name: ______________________

Date: ______________________

Exercise Entry

1. Type of exercise:
    - Running
    - Cycling
    - Swimming
    - Walking

- Other:

2. Duration of Exercise (in minutes): ______________________
3. Perceived intensity rating (1-5):

   (1 = Very Light, 2= Light, 3 = Moderate, 4 = Hard, 5 = Maximum Effort)

Note: If none of the provided intensity ratings feel accurate, please indicate this in the notes/comments.

4. Notes/Comments:
   - ______________________
   - ______________________

Appendix E: Setup and Instructions for N-Back Task

Task Overview: The n-back task was administered using Brain Workshop software, a tool designed to evaluate working memory by requiring participants to recall sequences of stimuli presented at specified intervals. The task involved two variations: visual and auditory n-back sequences.

Setup Instructions

1. Software installation: Brain Workshop software was installed on each participant's computer.
2. Task configuration:
   - Interval level: Each session was set to a two-back or three-back configuration, based on the study's design.

- Stimulus type: Participants completed either a visual n-back (identifying the position of visual stimuli) or an auditory n-back (recognizing a sound sequence).
- Session length: Each session was configured to last approximately five minutes, automatically transitioning through trials.

3. Quiet Environment: It is recommended that participants complete this task in a quiet, distraction-free environment to ensure accuracy.

Participant Instructions:

1. Starting the task: Participants opened the Brain Workshop software and selected the assigned n-back level for that session (two-back or three-back).
2. Responding to stimuli:
   - Visual task: Participants pressed a designated key if the current visual stimulus matched the one shown "n" steps earlier.
   - Auditory task: Participants pressed a designated key if the current auditory stimulus matched the sound heard "n" steps earlier.
3. Recording accuracy and response Time: Brain Workshop automatically recorded each participant's accuracy (percentage of correct responses) and response time per trial.
4. Saving results: Each session's data, including response accuracy and latency, was saved automatically in a digital format for later analysis. If any issues arise with automatic saving, participants should manually save their results and create a backup.