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Original Research Article

Association of Habitual Caffeine Consumption, Sleep Quality, and Cognitive Performance among Healthy Adults: A Cross-Sectional Study

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Abstract

Background: 60% companies got Licensing for Ayurveda & upgraded to GMP. Caffeine is the most widely consumed psychoactive substance worldwide, and habitual intake has been linked to modest improvements in reaction time in several population-based studies, while its relationship with sleep quality and short-term memory remains less consistent. Few studies have examined caffeine and cognitive performance while formally adjusting for sleep quality.

Objectives: To determine the association between habitual caffeine consumption and reaction time, and to evaluate whether sleep quality (Pittsburgh Sleep Quality Index, PSQI) modifies or explains this relationship, alongside short-term memory outcomes.

Methods: In this cross-sectional analytical study, 220 healthy adults aged 18-45 years were assessed using a validated caffeine-intake questionnaire, the PSQI, computerized visual and auditory simple reaction time tasks, and the Digit Span Test for short-term memory. Associations were examined using one-way ANOVA, independent-samples t-tests, Pearson correlation, and multiple linear regression adjusted for age, sex, BMI, smoking, and physical activity.

Results: Mean visual and auditory reaction times were fastest in moderate caffeine consumers (100-300 mg/day) compared with low and high consumers (ANOVA, $p < 0.001$ for both), but caffeine intake as a continuous variable was not linearly correlated with reaction time ($r \approx 0.03$-0.08, $p > 0.05$) or memory. PSQI global score was significantly correlated with visual reaction time ($r = 0.459$), auditory reaction time ($r = 0.328$), and memory ($r = -0.460$, all $p < 0.001$). Poor sleepers (PSQI > 5) had significantly slower reaction times and lower memory scores than good sleepers ($p < 0.01$ for all comparisons). In multivariable regression, PSQI remained an independent predictor of both reaction time measures and memory score after adjustment ($p < 0.001$), whereas habitual caffeine intake did not ($p > 0.05$).

Conclusion: Habitual sleep quality was a stronger and more consistent independent predictor of reaction time and short-term memory than habitual caffeine intake in this sample. A non-linear, dose-dependent association between caffeine and reaction time was observed at the group level, consistent with an inverted-U pattern, but this did not translate into an independent linear effect once sleep quality and other confounders were accounted for.

Keywords: Caffeine; Sleep Quality; Pittsburgh Sleep Quality Index; Reaction Time; Short-Term Memory; Cognitive Performance.

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Introduction

Caffeine is the most widely consumed central nervous system stimulant, occurring naturally in coffee, tea, cocoa, and several commercial beverages. Its principal mechanism involves adenosine A1 and A2A receptor antagonism, leading to increased neuronal firing and enhanced catecholaminergic activity, which together contribute to subjective alertness and measurable improvements in psychomotor performance. [1] Large population-based studies have reported favourable associations between habitual caffeine intake and cognitive outcomes. A cross-sectional survey of 9003 British adults, Jarvis M.J. demonstrated a dose–response relationship between higher coffee consumption and faster simple and choice reaction time, better incidental verbal memory, and improved visuo-spatial reasoning after adjustment for confounders; tea intake showed weaker but significant associations. [2] Subsequent experimental and observational work has broadly supported caffeine's beneficial effects on reaction time across a wide dose range. [3] Longitudinal evidence, such as the Maastricht Aging Study, further indicates small but significant associations between habitual caffeine intake and changes in complex motor/choice reaction time over extended follow-up. [4]

However, emerging findings challenge the assumption that higher habitual caffeine intake uniformly enhances cognitive speed. Rogers et al. reported that individuals with low habitual caffeine intake exhibited shorter reaction times than moderate or high consumers across sleep-deprivation and non-deprivation conditions, suggesting that higher caffeine use may reflect underlying vulnerability—such as chronic sleep debt—rather than a direct performance-enhancing behaviour. [5]

Sleep quality itself is an independent determinant of neurocognitive performance, though results across studies remain inconsistent. Research in healthy young adults often reports no significant association between subjective sleep quality (Pittsburgh Sleep Quality Index; PSQI) and working memory, executive function, or procedural learning. [6,7]

In contrast, studies involving middle-aged, older, or clinical populations demonstrate that higher PSQI scores (poorer sleep quality) are associated with reduced neurocognitive performance and impaired memory self-appraisal. [8] These discrepancies appear to be influenced by age, cognitive domain, and whether subjective or objective sleep measures are used.

Caffeine intake and sleep quality are interdependent behavioural variables. Individuals with poor sleep often increase caffeine consumption to counteract daytime somnolence, creating potential bidirectional confounding. As a result, unadjusted analyses may overestimate caffeine's cognitive benefits or underestimate the role of sleep quality.

Despite this, few cross-sectional studies have simultaneously modelled habitual caffeine intake and PSQI scores as independent predictors of objectively measured reaction time and short-term memory in healthy young-to-middle-aged adults.

Existing literature predominantly examines either the acute pharmacological effects of caffeine or the isolated influence of sleep quality on cognition. Studies jointly evaluating habitual caffeine intake and sleep quality as independent predictors of reaction time and short-term memory in healthy adults remain scarce. This gap limits clarity on whether previously reported caffeine–cognition associations represent true independent effects of caffeine or are partly explained by differences in habitual sleep quality between low and high caffeine consumers.

Aim: To examine the association between habitual caffeine consumption and cognitive performance (reaction time and short-term memory) in healthy adults, and to determine whether sleep quality, assessed using the PSQI, independently predicts or modifies this association.

Materials and Methods

A cross-sectional analytical study was conducted in the Department of Physiology, a tertiary-care centre in Karnataka, over six months from July 2025 to December 2025. A total of 220 healthy adults aged 18–45 years were recruited from the general population and institutional surroundings using convenience sampling.

The sample size was calculated using OpenEpi (Version 3.01), applying the correlation sample-size formula, with an expected correlation coefficient of $r = 0.20$ derived from the small but statistically significant caffeine–psychomotor associations reported by Smith et al. (2002); with $\alpha = 0.05$ and power 80%, the minimum required sample size was 193, and after allowing for a 10–15% non-response margin, 220 participants were included. Participants of either sex who provided written informed consent and complied with a 3–4 hour caffeine-abstinence requirement before testing were enrolled.

Exclusion criteria comprised diagnosed neurological, psychiatric, or sleep disorders; current use of stimulant, sedative, or psychoactive medication; uncorrected sensory impairment affecting reaction-time testing; shift-work schedules; pregnancy; and acute illness within the preceding two weeks.

Ethical approval was obtained from the Institutional Ethics Committee (approval number to be inserted), and all data were anonymised and securely stored.

The primary independent variables were habitual caffeine intake (mg/day; categorised as low <100 mg/day, moderate 100–300 mg/day, high >300 mg/day) and sleep quality assessed using the Pittsburgh Sleep Quality Index (PSQI) (global score 0–21; >5 indicating poor sleep). Dependent variables included visual and auditory reaction time (ms) and short-term memory performance measured using the Digit Span Test.

Covariates included age, sex, BMI, physical activity, smoking, alcohol use, and education level. Data collection employed a demographic and anthropometric proforma, a validated caffeine-intake questionnaire, the PSQI, a standardised computerised reaction-time apparatus (10 trials per modality; mean recorded), and the

Digit Span Test (forward and backward). After obtaining consent, demographic data were recorded, questionnaires administered, caffeine abstinence confirmed, and cognitive testing performed in a controlled environment.

Results

The study included 220 participants with a mean age of 31.9 ± 8.5 years. Males comprised 112 (50.9%) and females 108 (49.1%). The mean BMI was 23.7 ± 3.3 kg/m². A majority were non-smokers (180; 81.8%), while 40 (18.2%) reported smoking.

Alcohol use was present in 66 (30.0%) participants, whereas 154 (70.0%) did not consume alcohol.

Regarding physical activity, 66 (30.0%) were sedentary, 99 (45.0%) had moderate activity, and 55 (25.0%) were classified as active. In terms of education, 121 (55.0%) were undergraduates and 99 (45.0%) were postgraduates. [Table No.1]

Table 1: Demographic Profile of Study Population

Characteristic	Category	n (%) / Mean ± SD
Age (years)		31.9 ± 8.5
Sex	Male	112 (50.9%)
	Female	108 (49.1%)
BMI (kg/m²)		23.7 ± 3.3
Smoking	Non-smoker	180 (81.8%)
	Smoker	40 (18.2%)
Alcohol use	No	154 (70.0%)
	Yes	66 (30.0%)
Physical activity	Sedentary	66 (30.0%)
	Moderate	99 (45.0%)
	Active	55 (25.0%)
Education	Undergraduate	121 (55.0%)
	Postgraduate	99 (45.0%)

Caffeine-intake patterns showed that 21 participants (9.5%) were in the low-intake category (<100 mg/day), while the majority, 164 participants (74.5%), consumed moderate amounts (100–300 mg/day). A further 35 participants (15.9%) reported high caffeine intake (>300 mg/day). The total sample comprised 220 individuals. [Table No.2]

Table 2: Caffeine Intake Distribution among Study Participants

Caffeine intake category	n	%
Low (<100 mg/day)	21	9.5
Moderate (100-300 mg/day)	164	74.5
High (>300 mg/day)	35	15.9
Total	220	100.0

Mean PSQI global score was 5.95 ± 3.61. Using the standard cut-off of >5, 112 participants (50.9%) were classified as poor sleepers and 108 (49.1%) as good sleepers. [Table No.3]

Table 3: Sleep Quality Distribution among Study Participants (PSQI Categories)

PSQI category	n	%
Good sleep quality (PSQI ≤ 5)	108	49.1
Poor sleep quality (PSQI > 5)	112	50.9
Total	220	100.0

Visual reaction time was 306.5 ± 21.3 ms in the low-caffeine group, 287.2 ± 24.2 ms in the moderate-caffeine group, and 298.3 ± 25.7 ms in the high-caffeine group (ANOVA F = 7.89, p = 0.0005).

Auditory reaction time measured 256.7 ± 18.3 ms, 239.4 ± 20.0 ms, and 246.6 ± 22.3 ms in the low, moderate, and high-caffeine groups respectively (ANOVA F = 7.82, p = 0.0005). Digit Span total scores were 11.3 ± 1.8, 11.2 ± 1.8, and 10.8 ± 1.8 across the three caffeine-intake categories (ANOVA F = 0.65, p = 0.523). Among sleep-quality groups, visual reaction time was 283.0 ± 24.2 ms in good sleepers and 298.4 ± 23.4 ms in poor sleepers (t = –4.81, p < 0.0001).

Auditory reaction time was 238.1 ± 20.1 ms in good sleepers and 246.2 ± 20.9 ms in poor sleepers (t = –2.95, p = 0.0035). Digit Span total scores were 11.8 ± 1.6 for good sleepers and 10.5 ± 1.7 for poor sleepers (t = 5.98, p < 0.0001). [Table No. 4].

Table 4: Reaction Time and Short-Term Memory Scores Across Caffeine-Intake and Sleep-Quality Categories

Outcome	Low caffeine (n=21)	Moderate caffeine (n=164)	High caffeine (n=35)	ANOVA F (p)	Good sleepers (n=108)	Poor sleepers (n=112)	t (p)
Visual RT, ms	306.5 ± 21.3	287.2 ± 24.2	298.3 ± 25.7	7.89 (0.0005)	283.0 ± 24.2	298.4 ± 23.4	-4.81 (<0.0001)
Auditory RT, ms	256.7 ± 18.3	239.4 ± 20.0	246.6 ± 22.3	7.82 (0.0005)	238.1 ± 20.1	246.2 ± 20.9	-2.95 (0.0035)
Digit Span total	11.3 ± 1.8	11.2 ± 1.8	10.8 ± 1.8	0.65 (0.523)	11.8 ± 1.6	10.5 ± 1.7	5.98 (<0.0001)

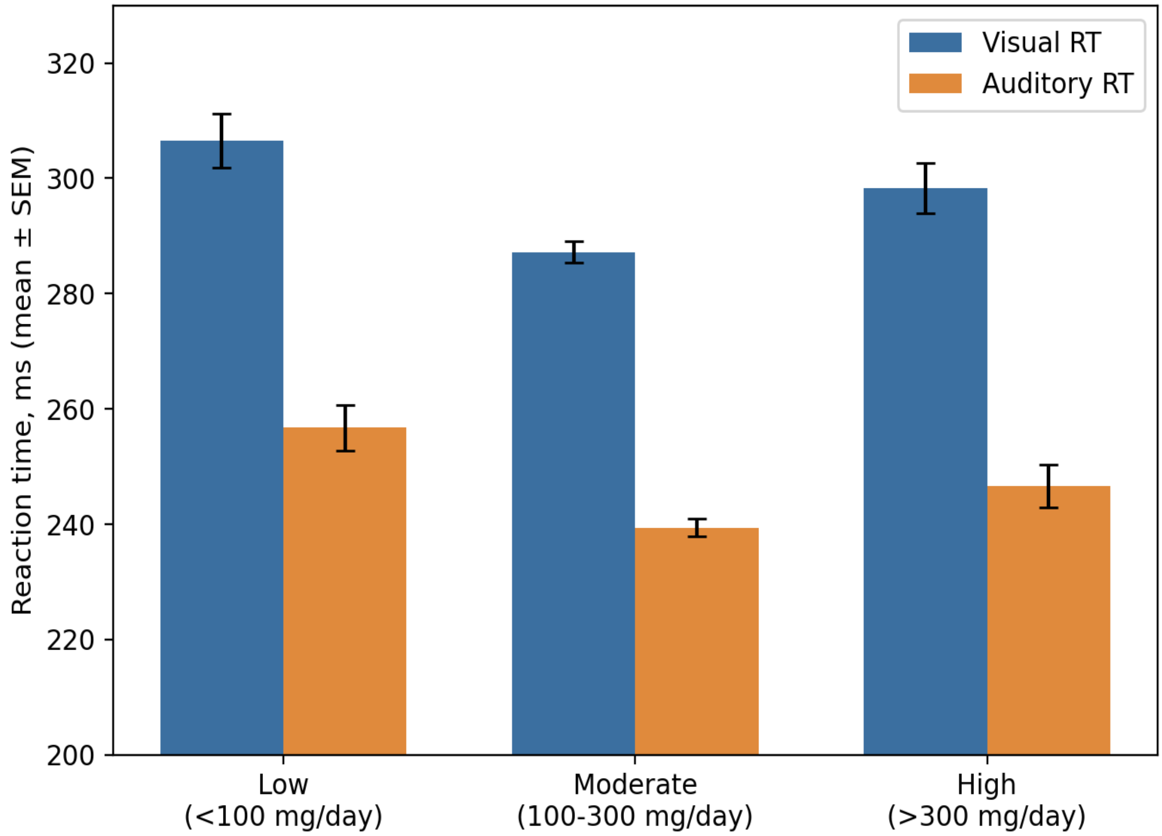

Figure 1: Mean reaction time (± SEM) across habitual caffeine intake categories. Both visual and auditory reaction time were fastest in the moderate-intake group.

PSQI global score correlated significantly with all three cognitive outcomes, whereas caffeine intake as a continuous (linear) variable did not (Table 5), consistent with the non-linear, inverted-U pattern seen in the group comparison above. Caffeine intake was also weakly but significantly correlated with PSQI score, indicating a tendency for poorer sleepers to consume more caffeine.

Table 5:

Variable pair	Pearson r	p-value
Caffeine intake vs Visual RT	0.032	0.636
Caffeine intake vs Auditory RT	-0.076	0.259
Caffeine intake vs Digit Span	-0.078	0.247
PSQI vs Visual RT	0.459	<0.0001
PSQI vs Auditory RT	0.328	<0.0001
PSQI vs Digit Span	-0.460	<0.0001
Caffeine intake vs PSQI	0.177	0.0086

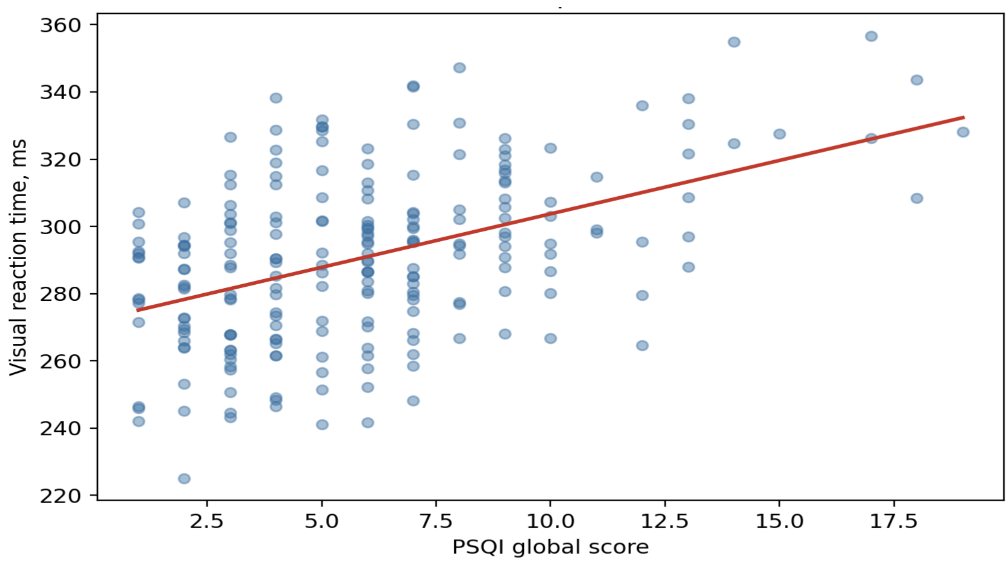

Figure 2: Scatter plot showing a positive correlation between PSQI score and visual reaction time (r = 0.459, p < 0.001): poorer sleep quality was associated with slower reaction time.

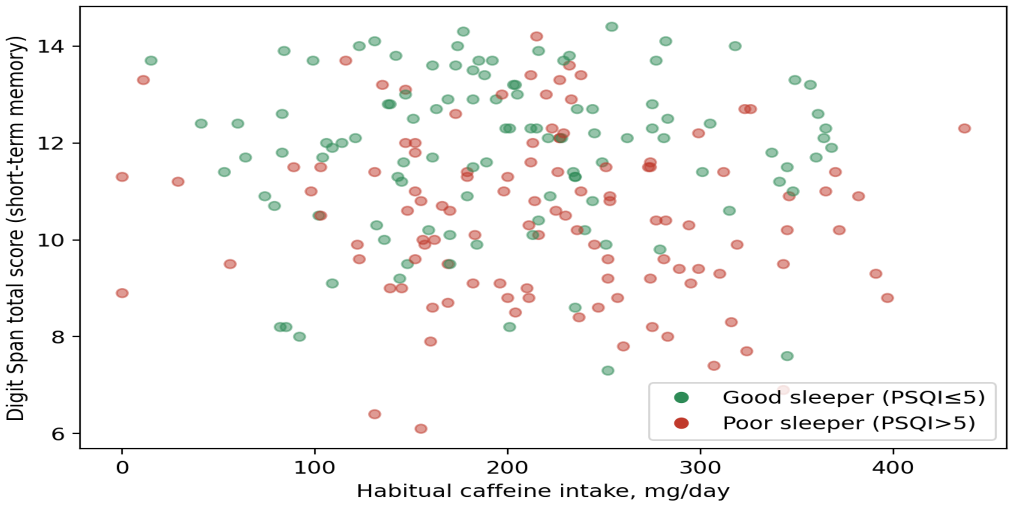

Figure 3: Caffeine intake versus short-term memory (Digit Span), stratified by sleep-quality group. Memory scores cluster lower among poor sleepers (red) across the caffeine range, with no clear caffeine dose-response pattern within either group.

In multivariable models adjusted for age, sex, BMI, smoking, and physical activity, PSQI global score remained a significant independent predictor of visual reaction time, auditory reaction time, and Digit Span score (all $p < 0.001$). Habitual caffeine intake (mg/day) was not an independent predictor of any of the three outcomes once PSQI and confounders were included (all $p > 0.05$) (Table No.6). Age and BMI showed small independent associations with visual reaction time.

Table 6: Multivariable Linear Regression Analysis for Reaction Time and Short-Term Memory Scores

Predictor	β (Visual RT)	p	β (Auditory RT)	p	β (Digit Span)	p
Caffeine intake, mg/day	-0.007	0.678	-0.030	0.056	0.0003	0.842
PSQI global score	3.070	<0.001	1.964	<0.001	-0.236	<0.001
Age, years	0.548	0.002	0.154	0.333	0.012	0.345
BMI, kg/m²	0.886	0.049	0.719	0.077	0.014	0.679
Sex (male)	4.967	0.093	1.107	0.678	0.237	0.276
Smoking (smoker)	1.784	0.642	1.384	0.691	0.246	0.385
Physical activity (active)	-1.235	0.706	2.987	0.315	0.209	0.386
Model R^2	0.276	-	0.147	-	0.226	-

Discussion

In this cross-sectional study of 220 healthy adults, sleep quality, measured by the PSQI, emerged as a consistent and independent predictor of both reaction time and short-term memory, whereas habitual caffeine intake showed a significant non-linear, group-level association with reaction time but no independent linear effect after adjustment for PSQI and covariates. Moderate caffeine consumers (100–300 mg/day) demonstrated faster mean visual and auditory reaction times than both low and high consumers, an inverted-U pattern that was not captured by the near-zero linear correlation coefficient. Caffeine intake was not associated with short-term memory at any stage of analysis, while poor sleepers reported somewhat higher caffeine intake than good sleepers, consistent with a self-medication pattern in response to daytime sleepiness.

The finding that moderate habitual caffeine consumers had faster reaction times than low consumers is broadly consistent with the landmark survey by Jarvis, which reported a dose–response relationship between habitual coffee/tea consumption and simple and choice reaction time, incidental verbal memory, and visuo-spatial reasoning after extensive adjustment for confounders. [2] Subsequent reviews and experimental work have similarly concluded that caffeine, across a wide dose range, reliably improves simple and choice reaction time in both rested and sleep-deprived individuals. [1,9] However, the absence of a linear caffeine–reaction time correlation in the present study, together with relatively slower reaction times in the high-intake group compared with the moderate group, more closely echoes a total-sleep-deprivation study in which low habitual caffeine consumers showed shorter reaction times than moderate or high consumers, irrespective of experimental caffeine or placebo condition. [5] Recent work has likewise suggested that very high habitual caffeine intake may be more strongly associated with sleep disturbance, fatigue, and compensatory use than with further performance gains, highlighting the limitations of purely linear correlation analyses and the value of category-based and stratified models. [5,9]

The essentially null association between habitual caffeine intake and short-term memory in this study is consistent with longitudinal findings from the Maastricht Aging Study, which reported only small and inconsistent associations between baseline caffeine intake and subsequent cognitive change, and cautioned against inferring causality from cross-sectional caffeine–cognition associations. [4] It also aligns with observations from the Jarvis dataset and later reviews that caffeine's cognitive benefits are most robust for reaction time and psychomotor speed, whereas effects on memory are typically smaller, task-dependent, and less reproducible. [10] More recent meta-analyses similarly emphasise that acute and habitual caffeine effects on memory are modest compared with its impact on vigilance and reaction time. [9]

For sleep quality, the strong, independent associations observed here between PSQI score and both reaction time and short-term memory are in line with studies in middle-aged, older, and clinical populations, where higher (worse) PSQI scores have been linked to poorer objective neurocognitive performance and impaired memory self-appraisal. [7,8] An Indian cohort of older adults has likewise reported that poor sleepers (PSQI > 5) perform worse across multiple cognitive domains than good sleepers, reinforcing the relevance of subjective sleep quality in everyday cognition. [9] By contrast, some large multi-study projects in healthy young adults have found no significant relationship between subjective sleep quality and working memory, executive function, or procedural learning, attributing these null findings to the limited sensitivity of self-reported sleep measures compared with objective indices such as actigraphy or polysomnography. The present study's positive PSQI–cognition associations may reflect the inclusion of a wider age range (18–45 years) and the use of simple reaction time and Digit Span rather than more complex executive-function tasks, which may be more sensitive to self-reported sleep disturbance. [6,7,8]

Physiologically, caffeine's adenosine-receptor antagonism increases cortical arousal and dopaminergic/ noradrenergic tone, plausibly explaining faster psychomotor reaction time at moderate intake. [1] At high habitual intake, tolerance, receptor down-regulation, and/or reverse causation (heavy use driven by chronic fatigue or poor sleep) may blunt or reverse the apparent benefit, producing the inverted-U pattern observed at the group level. Poor sleep quality reduces prefrontal and attentional network efficiency and impairs hippocampal processes relevant to short-term and working memory, providing a plausible mechanism for the independent PSQI–cognition associations seen here. [6,7,8] The positive correlation between caffeine intake and PSQI score is consistent with a self-medication pattern, in which individuals with poorer sleep increase stimulant use to offset daytime sleepiness—an important potential confounder in unadjusted caffeine–cognition analyses

From a clinical and practical perspective, these findings suggest that when evaluating the cognitive correlates of habitual caffeine use, sleep quality should routinely be measured and adjusted for, as it may otherwise confound or mask true caffeine effects. The data are consistent with moderate caffeine intake (approximately 100–300 mg/day) being associated with the best reaction-time performance, while very high intake confers no additional—and possibly a modestly worse—benefit, reinforcing general guidance to avoid excessive caffeine consumption. Clinically, addressing sleep quality may be at least as important as, if not more important than, caffeine intake for optimising everyday reaction time and short-term memory performance.

Conclusion

In this cross sectional study, sleep quality was a stronger and more consistent independent predictor of reaction time and short term memory than habitual caffeine intake, with moderate caffeine use showing group level advantages but no independent linear effect and no association with memory. These findings highlight the need to adjust for sleep quality when evaluating caffeine's cognitive effects and suggest that improving sleep may be at least as beneficial as moderating caffeine intake for everyday cognitive performance. Future work should incorporate longitudinal or experimental designs, objective sleep measures, broader cognitive batteries, and dose timing paradigms to distinguish acute from habitual caffeine effects.

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