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Association Between Habitual Caffeine Intake and Delayed Onset Muscle Soreness Among Recreationally Active Females

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ABSTRACT

***Background**: Delayed onset muscle soreness (DOMS) is a common, self-limiting pain syndrome following unfamiliar or intense exercise and may influence training adherence in recreationally active females; caffeine is widely consumed and may modulate post-exercise pain perception through adenosine receptor antagonism.* ***Objective**: To determine the association between habitual caffeine intake and DOMS severity and to evaluate the relationship between physical activity level and DOMS severity among recreationally active females.* ***Methods**: A cross-sectional observational study was conducted among 126 females (18–25 years) recruited from three fitness facilities in Lahore, Pakistan. Habitual caffeine intake was assessed using the Caffeine Consumption Questionnaire and categorized as low (<100 mg/day) or moderate (100–300 mg/day). DOMS severity was measured using a Likert-type muscle soreness scale (no, mild, moderate, severe). Physical activity level was classified using the International Physical Activity Questionnaire (low, moderate, high). Associations were tested using chi-square analyses ($\alpha = 0.05$), with effect sizes reported as Cramér's V.* ***Results**: Mean age was 21.02 ± 2.02 years. DOMS was reported by 82/126 (65.1%), most commonly moderate (27.8%) and mild (23.0%). Caffeine intake was significantly associated with DOMS severity ($\chi^2 = 18.47$, df = 3, p = 0.001; Cramér's V = 0.38), with severe soreness more frequent in low versus moderate caffeine consumers (24.6% vs 4.6%). Physical activity level was associated with DOMS severity ($\chi^2 = 13.21$, df = 6, p = 0.038; Cramér's V = 0.23).* ***Conclusion:** Moderate habitual caffeine intake and higher physical activity levels were associated with lower DOMS severity in recreationally active females.*

Keywords
habitual caffeine intake; delayed onset muscle soreness; physical activity; females; recreational exercise; IPAQ; CCQ

INTRODUCTION

Participation in recreational physical activity is widely promoted because it improves cardiometabolic health, musculoskeletal fitness, and psychological well-being, and female participation in structured exercise—particularly resistance and higher-intensity training—continues to increase as these modalities become integrated into routine lifestyle and body-composition goals (1). However, an anticipated consequence of unfamiliar, high-load, or eccentrically biased exercise is delayed onset muscle soreness (DOMS), a self-limiting pain syndrome that typically emerges hours after exercise, peaks approximately 24–72 hours post-exertion, and resolves within several days, with symptom burden that can include tenderness, stiffness, and transient reductions in function (2). Beyond being uncomfortable, DOMS can have practical implications for adherence and progression in recreational exercisers; if soreness restricts range of motion, reduces force output, or discourages repeat training sessions, it may indirectly undermine consistency in physical activity—especially among individuals who are newer to resistance training or cycling between variable training intensities (2,3). Importantly, the repeated-bout effect indicates that individuals adapt over time to eccentric and multiarticular loading, generally experiencing less muscle damage and soreness with subsequent exposures, linking DOMS severity to training status and recent novelty of exercise stimuli (4).

Caffeine is among the most frequently consumed psychoactive substances worldwide and is habitually integrated into daily routines through coffee, tea, and commercial beverages, with population studies documenting substantial prevalence of daily use and patterns consistent with tolerance and dependence in habitual consumers (5,6). From a sports nutrition perspective, caffeine is also a well-established ergogenic aid, with evidence supporting improvements in alertness, perceived effort, and performance across endurance and strength contexts, largely via antagonism of adenosine receptors and downstream neuroendocrine effects (7). These same mechanisms provide a biologically plausible basis for caffeine to influence post-exercise pain perception, because adenosine signaling participates in nociception and central fatigue; accordingly, acute caffeine ingestion has been observed to modify perceived exertion and pain perception during strenuous exercise tasks (8). In addition, caffeine has been examined in relation to indirect markers of exercise-induced muscle damage and soreness, with systematic reviews indicating that caffeine can reduce pain outcomes in certain exercise-damage paradigms, although findings vary by protocol, dose, timing, and participant characteristics (9,10).

Despite this mechanistic plausibility and an expanding body of supplementation trials, there remains a clinically meaningful gap at the intersection of habitual dietary behavior and real-world recovery outcomes. Much of the caffeine–DOMS literature emphasizes acute supplementation under controlled exercise protocols, while fewer studies address whether habitual intake patterns—the practical exposure most relevant to recreational exercisers—are associated with DOMS severity under field conditions (9,10).

This gap is especially salient for recreationally active females, because female cohorts are often underrepresented in exercise-recovery research, and because factors such as training modality, weekly volume, and baseline activity status may confound or modify any observed association between caffeine intake and post-exercise soreness (3,4). For example, individuals with higher fitness or more consistent training exposure may report less severe DOMS due to the repeated-bout effect, and these same individuals may also differ systematically in caffeine habits, sleep routines, and exercise intensity preferences (3,4). Consequently, evaluating caffeine intake in isolation—without considering activity level—risks producing associations that are statistically significant yet not clinically interpretable.

Accordingly, the present study is designed to address a practical question in a clearly defined population using an observational framework aligned to PICO: in recreationally active females (Population), does habitual caffeine intake categorized as low versus moderate (Exposure), compared with lower habitual intake (Comparator), show an association with DOMS presence and severity following exercise, while also considering the participant's physical activity level as an important co-exposure and potential confounder (Outcome) (7,9,10).

The study justification rests on three converging needs: first, DOMS is common after novel or intense exercise and can transiently impair function (2); second, caffeine consumption is widespread and biologically capable of altering pain perception (6–8); and third, the translation of controlled-trial findings into everyday female recreational training settings remains limited, particularly when habitual intake and activity level coexist and may jointly influence soreness experiences (3,4,9,10).

The objective of this study, therefore, is to determine whether habitual caffeine intake is associated with DOMS severity among recreationally active females and to evaluate the relationship between physical activity level and DOMS severity within the same cohort. We hypothesize that moderate habitual caffeine consumers will report less severe DOMS than low habitual caffeine consumers, and that higher physical activity levels will be associated with lower DOMS severity after accounting for the habitual nature of exposure and the expected adaptation associated with training status (4,7,10).

MATERIAL AND METHODS

The present investigation was conducted as a cross-sectional observational study designed to examine the association between habitual caffeine intake, physical activity level, and delayed onset muscle soreness (DOMS) among recreationally active females. A cross-sectional design was selected to characterize real-world exposure patterns and symptom profiles within a defined population at a single time point, which is appropriate for assessing prevalence and associations where experimental manipulation is neither ethical nor feasible (11). Data collection was carried out over a three-month period following formal approval of the study protocol, and all procedures were implemented consistently throughout the study duration to minimize temporal variation.

The study was conducted at three fitness facilities located in Lahore, Pakistan, including Shapes Executive Gym, KASRAT Health and Fitness Club, and Akhara Gym. These sites were selected to capture a heterogeneous sample of recreationally active females engaged in aerobic, resistance, and mixed training modalities. Participants were recruited using a non-probability convenience sampling approach, whereby eligible individuals attending the facilities during the data collection period were invited to participate. Recruitment was conducted in person by the primary investigator, who provided a standardized verbal explanation of the study purpose and procedures. Written informed consent was obtained from all participants prior to enrollment, in accordance with ethical standards for human subject research (12).

Eligible participants were females aged 18 to 25 years who reported engagement in low-to-moderate intensity resistance training and/or aerobic physical activity for at least three days per week over the preceding year. Habitual caffeine intake was defined as consumption of at least one caffeinated beverage on five or more days per week, with total daily intake falling within the low-to-moderate range (<300 mg/day). Participants were additionally required to report a regular menstrual cycle over the previous six months to reduce hormonal variability that may influence pain perception or recovery (13).

Exclusion criteria were applied to minimize confounding from medical or lifestyle factors known to affect musculoskeletal pain, recovery, or caffeine metabolism, including pregnancy or postpartum status, use of oral contraceptives within the past month, heavy caffeine consumption (>350 mg/day), history of cardiovascular disease or uncontrolled hypertension, prior musculoskeletal injury or skeletal lesions, obesity (BMI ≥30 kg/m²), use of medications or supplements targeting musculoskeletal health, smoking or substance use, and the presence of clinically significant sleep disturbances as indicated by a Pittsburgh Sleep Quality Index score greater than 8 (14–16).

Data were collected using a structured, self-administered questionnaire battery completed on-site in a supervised setting to reduce missing or ambiguous responses. Demographic data included age and exercise characteristics such as type of activity and weekly training frequency. Habitual caffeine intake was assessed using the Caffeine Consumption Questionnaire, a validated instrument that quantifies average daily caffeine intake by capturing frequency and portion size of common caffeinated beverages and foods, which are subsequently converted into estimated milligrams of caffeine per day (17). Based on calculated intake, participants were categorized into low (<100 mg/day) and moderate (100–300 mg/day) caffeine intake groups, consistent with prior literature examining habitual consumption thresholds (18).

DOMS was assessed using a Likert-type muscle soreness scale, which measures perceived muscle soreness severity following exercise on an ordinal scale ranging from no soreness to severe soreness. Participants were instructed to rate soreness experienced after their most recent exercise sessions that resulted in post-exercise muscle discomfort, consistent with established subjective assessment approaches for DOMS in field-based studies (19). Additional items captured the anatomical location of soreness, timing of peak pain, associated symptoms (e.g., tenderness, fatigue, swelling, reduced strength), and activities perceived to have precipitated soreness. Physical activity level was evaluated using the International Physical Activity Questionnaire (IPAQ) short form, which classifies individuals into low, moderate, or high activity categories based on weekly energy expenditure expressed in metabolic equivalent minutes (20).

The primary outcome variable was DOMS severity, operationalized as an ordinal categorical variable derived from the Likert-type soreness scale. The primary exposure variable was habitual caffeine intake category (low vs. moderate). Physical activity level, as classified by IPAQ, was treated as a key covariate and secondary exposure given its established relationship with both DOMS severity and training adaptation. To address potential sources of bias, standardized eligibility screening was applied across all sites, questionnaires were administered in a uniform order, and data collection was conducted by the same investigator to reduce inter-observer variability. Restrictive inclusion and exclusion criteria were used to limit confounding related to injury, medication use, sleep disorders, and extreme caffeine exposure, while physical activity level was explicitly measured to permit analytical assessment of its relationship with DOMS (21).

The sample size of 126 participants was determined a priori based on estimates from comparable cross-sectional studies assessing DOMS prevalence and caffeine-related outcomes in physically active populations, providing adequate power to detect moderate associations using categorical statistical tests at a conventional alpha level of 0.05 (22). Data were entered and analyzed using IBM SPSS Statistics version 26. Continuous variables were summarized using means and standard deviations, while categorical and ordinal variables were summarized using

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frequencies and percentages. Associations between categorical variables, including caffeine intake category, physical activity level, and DOMS severity, were examined using chi-square tests of independence. Where appropriate, effect size estimates were derived to aid interpretation of clinical relevance. Statistical significance was set at $p < 0.05$. Records were reviewed for completeness at the time of collection to minimize missing data, and all analyses were conducted on complete cases.

Ethical approval for the study was obtained from the Institutional Research Ethics Board of the University of Lahore prior to commencement. The study adhered to the principles outlined in the Declaration of Helsinki, and participant confidentiality was maintained through anonymization of all data records. Participation was entirely voluntary, and participants were informed of their right to withdraw from the study at any point without consequence. Data integrity and reproducibility were ensured through standardized data collection instruments, predefined variable definitions, double-checking of data entry, and transparent reporting of analytical procedures, enabling replication by independent researchers (12).

RESULTS

Table 1 summarizes participant characteristics and exposure distributions for the full sample (n = 126). The mean age was 21.02 ± 2.02 years. With respect to training profile, 56 participants (44.4%) primarily performed aerobic exercise, 42 (33.3%) reported mixed aerobic and resistance training, and 28 (22.2%) reported resistance training as their main activity. Most participants trained 3–5 days/week (83/126; 65.9%), while 43/126 (34.1%) trained 5–7 days/week. Habitual caffeine intake (CCQ) was almost evenly distributed, with 65 participants (51.6%) categorized as low intake and 61 (48.4%) as moderate intake. IPAQ classification showed that 76 participants (60.3%) were moderately active, 30 (23.8%) were highly active, and 20 (15.9%) were in the low activity category.

Table 2 presents DOMS prevalence and key descriptive characteristics. Overall, 82/126 participants (65.1%) reported some level of soreness, while 44/126 (34.9%) reported no soreness. Moderate soreness was the most frequent severity category (35/126; 27.8%), followed by mild soreness (29/126; 23.0%) and severe soreness (18/126; 14.3%). DOMS was most commonly localized to the lower limbs, reported by 62 participants (49.2%), followed by the back (26; 20.6%) and upper limbs (25; 19.8%); chest soreness was least common (13; 10.3%). Regarding timing of severe pain, 70 participants (55.6%) reported pain "throughout the day," 30 (23.8%) reported severe pain primarily at night, and 26 (20.6%) reported severe pain primarily during daytime hours.

Table 3 details symptom patterns, perceived triggers, and recovery/practice behaviors. The most frequently endorsed symptoms were muscle tenderness (98/126; 77.8%) and muscle fatigue (92/126; 73.0%). More than half reported loss of strength (67/126; 53.2%), while reduced range of motion was reported by 37/126 (29.4%) and swelling by 30/126 (23.8%). Participants most often attributed DOMS to training-related novelty or high load: new exercises were reported as a precipitating factor by 97/126 (77.0%), heavy weight lifting by 95/126 (75.4%), high-intensity exercise by 92/126 (73.0%), and prolonged workouts by 88/126 (69.8%).

Regarding preventive practices, 86/126 (68.3%) reported warming up and 77/126 (61.1%) reported cooling down after practice; 79/126 (62.7%) reported having adequate breaks during training and the same proportion (79/126; 62.7%) reported sufficient daily water intake. For pain relief, hot water bath/fomentation was most commonly used (90/126; 71.4%), followed by active rest (76/126; 60.3%). Cold water bath was reported by 53/126 (42.1%), complete bed rest by 55/126 (43.7%), and continuing workouts "as before" was least common (23/126; 18.3%).

Table 4 provides inferential analyses for the study's primary associations. A statistically significant association was observed between caffeine intake category and DOMS severity ($\chi^2 = 18.47$, def. = 3, $p = 0.001$), with a moderate effect size (Cramér's V = 0.38). The contingency pattern indicated that severe soreness was more frequent among low caffeine consumers (15 vs 3), while mild soreness was more frequent among moderate caffeine consumers (22 vs 7), and "no soreness" was also more common in the moderate caffeine group (26 vs 18).Physical activity level was significantly associated with DOMS severity ($\chi^2 = 13.21$, def. = 6, $p = 0.038$), with a small-to-moderate effect size (Cramér's V = 0.23). In this crosstab, "no soreness" was most frequent in high activity participants (16) and moderate activity participants (26), while low activity participants reported comparatively fewer "no soreness" cases (2) and a higher count of severe soreness (6).

Table 1. Participant characteristics, training profile, caffeine intake, and physical activity level (n = 126).

Domain	Category / Statistic	n	% / Mean ± SD
Age	Age (years)		21.02 ± 2.02
Activity involvement	Resistance	28	22.2
Activity involvement	Aerobic	56	44.4
Activity involvement	Mixed	42	33.3
Training frequency	3–5 days/week	83	65.9
Training frequency	5–7 days/week	43	34.1
Habitual caffeine intake (CCQ)	Low	65	51.6
Habitual caffeine intake (CCQ)	Moderate	61	48.4
Physical activity level (IPAQ)	Low	20	15.9
Physical activity level (IPAQ)	Moderate	76	60.3
Physical activity level (IPAQ)	High	30	23.8

Table 2. DOMS prevalence and characteristics (n = 126).

Domain	Category	n	%
DOMS severity	No soreness	44	34.9
DOMS severity	Mild soreness	29	23.0
DOMS severity	Moderate soreness	35	27.8
DOMS severity	Severe soreness	18	14.3
DOMS location	Upper limb	25	19.8
DOMS location	Lower limb	62	49.2
DOMS location	Chest	13	10.3
DOMS location	Back	26	20.6
Timing of severe pain	Daytime only	26	20.6
Timing of severe pain	Night only	30	23.8
Timing of severe pain	Throughout the day	70	55.6

Table 3. DOMS symptoms, perceived precipitating activities, and recovery/practice behaviors (n = 126).

Section	Item	Yes n (%)	No n (%)	Notes
Symptoms	Muscle tenderness	98 (77.8)	28 (22.2)	
Symptoms	Muscle fatigue	92 (73.0)	34 (27.0)	
Symptoms	Loss of strength	67 (53.2)	59 (46.8)	
Symptoms	Reduced ROM	37 (29.4)	89 (70.6)	
Symptoms	Swelling	30 (23.8)	96 (76.2)	
Perceived triggers	New exercises	97 (77.0)	29 (23.0)	
Perceived triggers	Heavy weight lifting	95 (75.4)	31 (24.6)	
Perceived triggers	High-intensity exercise	92 (73.0)	34 (27.0)	
Perceived triggers	Prolonged workouts	88 (69.8)	38 (30.2)	
Practice behaviors	Warm-up	86 (68.3)	40 (31.7)	
Practice behaviors	Cool-down	77 (61.1)	49 (38.9)	
Practice behaviors	Adequate breaks	79 (62.7)	47 (37.3)	
Practice behaviors	Adequate hydration	79 (62.7)	47 (37.3)	
Pain relief methods	Hot water bath/fomentation	90 (71.4)	36 (28.6)	
Pain relief methods	Active rest	76 (60.3)	50 (39.7)	
Pain relief methods	Cold water bath	53 (42.1)	73 (57.9)	
Pain relief methods	Continue workout	23 (18.3)	103 (81.7)	
Pain relief methods	Complete bed rest	55 (43.7)	71 (56.3)	

Table 4. Associations between caffeine intake, physical activity level, and DOMS severity.

Association	Contingency summary	χ^2	df	p-value
Caffeine intake × DOMS severity	Counts: No (18 vs 26), Mild (7 vs 22), Moderate (21 vs 14), Severe (15 vs 3) [Low vs Moderate caffeine]	18.47	3	0.001
IPAQ level × DOMS severity	Counts: No (16,26,2), Mild (5,20,4), Moderate (6,21,8), Severe (3,9,6) [High, Moderate, Low IPAQ]	13.21	6	0.038
Caffeine intake × IPAQ level	Counts: High (6 vs 24), Moderate (45 vs 31), Low (14 vs 6) [Low vs Moderate caffeine]	9.02	2	0.011

Finally, caffeine intake category was significantly associated with IPAQ activity level ($\chi^2 = 9.02$, df = 2, p = 0.011), with a moderate effect size (Cramér's V = 0.27). In particular, moderate caffeine intake was more common among highly active participants (24 vs 6), whereas low caffeine intake predominated among those with moderate activity (45 vs 31) and low activity (14 vs 6).

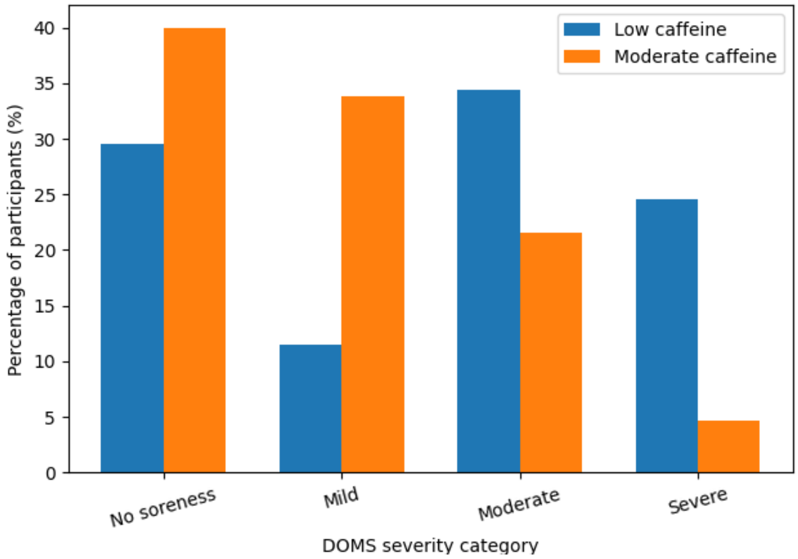

Figure 1 Gradient Distribution of DOMS Severity Across Habitual Caffeine Intake Levels

The figure illustrates a graded redistribution of delayed onset muscle soreness (DOMS) severity across habitual caffeine intake categories, revealing a clinically meaningful shift toward lower symptom burden among moderate caffeine consumers. Participants with moderate caffeine intake demonstrated a higher proportion of no soreness (40.0%) and mild soreness (33.8%) compared with low caffeine consumers (29.5% and 11.5%, respectively). In contrast, moderate and severe soreness were more prevalent among low caffeine consumers, accounting for 34.4% and 24.6% of cases, respectively, compared with 21.5% and 4.6% among moderate caffeine consumers. Notably, the proportion of severe DOMS was more than fivefold higher in the low caffeine group (24.6%) than in the moderate caffeine group (4.6%). This distribution highlights a clear severity gradient, suggesting that moderate habitual caffeine intake is associated with a clinically relevant shift away from moderate-to-severe DOMS toward milder or absent symptoms, complementing the statistically significant association observed in inferential analyses ($\chi^2 = 18.47$, p = 0.001, Cramér's V = 0.38).

DISCUSSION

The present study investigated the association between habitual caffeine intake, physical activity level, and delayed onset muscle soreness (DOMS) among recreationally active females, providing novel field-based evidence in a population that remains underrepresented in exercise recovery research. The findings demonstrate a high overall prevalence of DOMS (65.1%), with most affected participants reporting mild to moderate

severity, a pattern consistent with prior observational studies in recreational and resistance-trained populations (23,24). Importantly, the distribution of DOMS severity varied significantly according to habitual caffeine intake, with moderate caffeine consumers exhibiting a clear shift toward lower symptom severity compared with low caffeine consumers. This association was supported by both inferential statistics ($\chi^2 = 18.47$, $p = 0.001$) and a moderate effect size (Cramér's V = 0.38), suggesting not only statistical but also clinical relevance.
The observed relationship between habitual caffeine intake and DOMS severity aligns with existing mechanistic and experimental literature indicating that caffeine modulates pain perception through non-selective antagonism of adenosine receptors within the central nervous system (25). Adenosine plays a key role in nociception and fatigue signaling; thus, habitual blockade of these receptors may elevate pain thresholds and attenuate soreness perception following exercise-induced muscle damage (26). While much of the prior literature has focused on acute caffeine supplementation administered before or after standardized exercise protocols, systematic reviews and meta-analyses have reported modest but consistent reductions in perceived muscle soreness with caffeine ingestion during the 24–72 hour recovery window (9,10). The current findings extend this evidence by suggesting that habitual, rather than acute, caffeine exposure may be associated with lower DOMS severity under real-world training conditions, where individuals are exposed to repeated exercise bouts of varying intensity.
A key contribution of this study is the concurrent evaluation of physical activity level, which was also significantly associated with DOMS severity ($\chi^2 = 13.21$, $p = 0.038$). Participants classified as moderately or highly active more frequently reported no or mild soreness, whereas those with low activity levels demonstrated a higher proportion of moderate and severe DOMS. This pattern is consistent with the well-established repeated-bout effect, whereby repeated exposure to eccentric and multiarticular loading induces structural and neural adaptations that reduce subsequent muscle damage and soreness (4,27). These findings reinforce the importance of training status as a determinant of DOMS and highlight physical activity level as a potential confounder or effect modifier in studies examining nutritional or recovery-related exposures.
Notably, habitual caffeine intake was also significantly associated with physical activity level, with moderate caffeine consumption more prevalent among highly active participants. This interrelationship suggests that caffeine intake and activity level may cluster as part of a broader behavioral phenotype characterized by higher training frequency, greater exercise tolerance, and possibly greater familiarity with recovery strategies. While the present cross-sectional design precludes causal inference, the findings underscore the importance of considering lifestyle and training behaviors simultaneously when interpreting associations between dietary exposures and musculoskeletal outcomes (28). Failure to account for physical activity level may overestimate or underestimate the independent contribution of caffeine to DOMS severity.
From a clinical and practical perspective, the results suggest that moderate habitual caffeine consumption (100–300 mg/day) is associated with a lower burden of post-exercise muscle soreness in recreationally active females, without evidence of increased severe DOMS. This is particularly relevant given concerns regarding excessive reliance on pharmacological analgesics for exercise-related pain management (29). However, the findings should not be interpreted as an endorsement of caffeine as a therapeutic intervention for DOMS, as excessive intake carries known risks related to sleep disruption, cardiovascular symptoms, and dependence (6,30). Instead, caffeine intake should be considered within a broader recovery framework that includes progressive training load, adequate hydration, sleep, and active recovery practices.
Several limitations warrant consideration. The cross-sectional design limits causal inference and is subject to recall bias, particularly in self-reported caffeine intake and soreness severity. DOMS was assessed using subjective measures rather than objective biomarkers of muscle damage, although subjective soreness remains the most clinically relevant outcome for exercisers (2). Additionally, unmeasured factors such as dietary protein intake, exact timing of caffeine consumption relative to exercise, and menstrual cycle phase may have influenced pain perception and recovery. Despite these limitations, the study's strengths include a clearly defined population, standardized instruments, and integrated analysis of caffeine intake and physical activity level, enhancing the interpretability of the findings.

CONCLUSION

In conclusion, delayed onset muscle soreness was highly prevalent among recreationally active females, with most participants experiencing mild to moderate symptoms. Habitual caffeine intake was significantly associated with DOMS severity, such that moderate caffeine consumers reported less severe soreness compared with low caffeine consumers. Physical activity level was also independently associated with DOMS, with moderate and high activity levels linked to milder symptom profiles. Together, these findings suggest that habitual caffeine consumption and regular physical activity may jointly influence post-exercise muscle soreness, underscoring the importance of considering lifestyle and training behaviors when addressing recovery and exercise adherence in recreationally active women.

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