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An investigation into the effects of weekly habitual and targeted caffeine consumption on adult runners' endurance, speed, and mood

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Abstract

BACKGROUND: Caffeine is a commonly consumed recreational drug which is also highly regarded as an ergogenic aid. Generally, users partake in sporadic and habitual caffeine consumption for functional benefits such as alertness or for social purposes, but targeted consumption prior to exercise is claimed to aid endurance, increase speed, and improve mood during exercise. OBJECTIVES: This questionnaire-based study aimed to evaluate the effect of targeted and randomised caffeine consumption on endurance, speed, and perceived mood in runners of varying levels. SUBJECTS: 489 subjects from 27 different countries (predominantly United States of America and United Kingdom) participated in the study (50.7% female, 89.0% white Caucasian, mean age 30.8 ± 8.6 years, and mean BMI 23.8 ± 4.0 kg·m^2). METHODS: Recruiting the study sample occurred using online running groups and forums. Subjects completed a three-part questionnaire to receive data on individual running distances, speed, and mood depending on timing of caffeine consumption. RESULTS: Total weekly running distance was significantly higher in targeted compared to sporadic caffeine consumers (p=0.001) and in participant's longest run of the week, those who targeted their caffeine consumption ran further (p=0.002). Caffeine consumption within an hour prior to shorter distance runs resulted in significantly greater motivation, energy, and effort scores (p<0.05) but not in longer runs (p>0.05). CONCLUSIONS: Targeted caffeine consumption was associated with greater total weekly distance, distance during longer runs, and some improved moods during shorter runs. There is scope for runners to meet goals by utilising specific caffeine consumption timings.

Keywords: caffeine, running, ergogenic aid, sporting performance, endurance, mood, speed, distance, runners.

Caffeine overview

As one of the world's best known recreational drugs, caffeine is regularly consumed by around 90% of adults in Western countries (Fulgoni *et al*, 2015). Caffeine's popularity is hardly surprising given its extensive list of plant sources, including coffee, tea, and cocoa, which form the basis of most caffeinated beverages (Guest *et al*, 2021). Although 96% of caffeine consumption can be attributed to drinks such as coffee and tea, the compound is also present in chocolate, medication, sweets, and sports supplements (Durrant, 2002; Mitchell *et al*, 2014). Part of the methylxanthine class, caffeine elicits a stimulant effect on the central nervous system and enhances alertness, which is why it has become a versatile aid in both social and sporting situations (Nehlig *et al*, 1992). Once absorbed via the gastrointestinal tract, caffeine reaches peak plasma concentrations within the range of 40 to 60 minutes, meaning effects are rapid (James, 2004). Contemporary research discusses methods in which caffeine modifies central nervous system neurotransmission by blocking adenosine receptors, elevating heart rate and blood pressure (Cauli and Morelli, 2005; Rogers and Dinges, 2005). According to a recent publication from the International Society of Sports Nutrition Position Stand by Guest *et al* (2021), the binding mechanism of caffeine to adenosine receptors increases availability of neurotransmitters such as serotonin, dopamine, acetylcholine, and norepinephrine (instead of adenosine's down regulatory effect) and initiates positive effects on mood and alertness (Salamone *et al*, 2018).

Caffeine as an ergogenic aid

Ergogenic aids, otherwise described as substances which enhance physical or mental performance to provide a desirable sporting advantage, exist in a range of forms (Thein *et al*, 1995). For example, such aids can be physical objects like clothing, or ingestible pharmacological substances which legally or illegally enhance performance. Caffeine has been widely studied for use as an effective nutritional ergogenic aid since around the 1970s because of promising physiological effects (Grandjean, 1997). Research has centred on caffeine induced improvements to endurance, either through increased time to exhaustion or by decreased effort perception, and often in populations of runners, swimmers, and cyclists (Keisler and Armsey, 2006; Rogers and Dinges, 2005).

One early study by Costill *et al* (1978) found that ingestion of 330mg of caffeine promoted an increase in exercise duration of 75 to 96 minutes in a cycle ergometer test to exhaustion. More recently, Prins *et al* (2016) combined performance and mood state and found that runners who consumed a sugar free Red Bull energy drink within an hour before a 5km time trial were 30 seconds faster than those who received a caffeine-free placebo ($p = 0.016$). According to Tarnopolsky and Cupido (2000), ingesting caffeine within an hour before exercise also saw performance benefits for endurance activities with a duration between 30 and 120 minutes. Many studies also observed participant's perceptions of the activity, most using rating of perceived exertion (RPE) scores, in accordance with their caffeine consumption. Doherty and Smith (2005) conducted a meta-analysis of 21 studies where RPE scores were reduced by 5.6% in caffeine consuming groups compared to the corresponding placebos (95% CI, -4.5% to -6.7%). However, there is still conflicting evidence for effort perception linked to caffeine consumption. Both Prins *et al* (2016) and Candow *et al* (2009) found no significant difference in RPE scores when consuming a sugar free Red Bull energy drink prior to exercise ($p>0.05$).

In summary, current research has varied outcomes, particularly around perceived exercise effort post caffeine consumption in relation to running specifically. Whilst evidence for caffeine enhancing exercise performance is strong and the focus of many meta-analyses and systematic reviews, often these studies are conducted using one caffeine source like the Red Bull study by Prins *et al* (2016) or conducted solely amongst competitive/trained individuals such as Duncan *et al* (2012). Furthermore, many current studies use smaller participant groups, for example Prins *et al* (2016) used a small population of 18 participants with similar characteristics, thus limiting the diversity of the results.

Caffeine for running endurance and perceived mood

The present questionnaire-based study aims to overcome the restraints of lab-based research in terms of participant numbers to reach a significantly greater population, thus enhancing representation of the diverse running community of both recreational and competitive runners worldwide. Caffeine consumption will be generalised in an attempt to reflect the range of caffeine sources consumed in everyday life instead of limiting the study to just one source. Additionally, the rationale of this study involves a strong consideration for other mood perceptions rather than effort alone to gain a deeper understanding of any changes to the feelings which drive a runner to keep running and further their endurance capabilities. It is hypothesised that those who time their caffeine consumption around their running sessions and competitions will run greater distances when aiming for endurance, run faster, and experience positive mood benefits (heightened motivation, happiness, focus, energy, and reduced effort perception). As one of the most ingested ergogenic aids, research is vital to ensure those who supplement their sporting activities with caffeine are within safe limits and receiving the desired effect. Moreover, caffeine has not always been so freely used for sports performance and was listed as a controlled substance by the World Anti Doping Agency (WADA) until 2004 (Van Thuyne and Delbeke, 2006). As a result, continued research is important to ensure the lifted ban was justified and that caffeine is safely used as a tool rather than an unfair advantage.

Study aims

1. Evaluate the effect of targeted and randomised caffeine consumption on endurance running performance amongst competitive and recreational runners.
2. Evaluate the effect of targeted and randomised caffeine consumption on mood perception (motivation, energy, happiness, focus, and effort) amongst competitive and recreational runners.

Methodology

Sample

In total, 489 participants took part in the study (50.7% female, 89.0% white Caucasian, mean age 30.8 ± 8.6 years, and mean BMI 23.8 ± 4.0 kg·m^2). This population amassed a total of 27 countries (predominantly 63.2% United States of America, 12.7% United Kingdom, 8% Canada, 2.2% Netherlands, 2.2% Australia, and 11.7% from other regions). Recruitment involved link sharing on online running groups, communities, and forums, utilising social media platforms including Reddit and Facebook. In each instance the questionnaire link was accompanied by study information and requirements whilst also meeting the rules and regulations of individual forums. Criteria for inclusion were an age ≥18 years, participating in running for leisure or competitively, and having a method of tracking activity such as a smartwatch or smart phone.

Ethical approval for the study was granted by the Research Ethics and Integrity Committee of the University of Plymouth Faculty of Science and Engineering. All participants provided informed consent before completing the questionnaire. Full risk assessment measures were taken to minimise risk to both the researcher and participants, with particular emphasis on taking regular breaks from computer screens and desks to prevent eye and back strain.

Study design

Participants completed a three-part questionnaire (general information, caffeine consumption, and running habits) using the JISC online survey platform. The general information section focused on gathering general health details including age, weight, height, gender, ethnicity, and smoking status. This enabled calculation of categorical health measures like BMI and allowed for a clearer understanding of the lifestyles and characteristics of the sample. With few exclusion criteria and worldwide exposure, these questions also provided the opportunity to define this extremely diverse population.

Caffeine consumption was assessed in the following questionnaire section where participants were asked the frequency at which they consumed both caffeinated and decaffeinated drinks in the week prior to answering the survey. These included coffee, tea, energy drinks, pre-workout, and soft drinks, as well as sub-categories including different coffee and tea styles (barista style and home made). Participants were then asked whether they intentionally time their caffeine consumption before a running session for the purpose of enhancing their running performance or experience.

Aside from the main running segment of the questionnaire, participants were given a handful of questions about their motivations for running and type of running they partake in (competitive or leisure). Since the benefits of running can be so diverse, these questions were designed to gain an insight into what this population deem the greatest benefit to them (for example general fitness, losing weight, improved mental health or to achieve a running milestone). Other useful information was gathered surrounding additional exercise the individuals were involved in for leisure or competitively. Any general physical activity data represented daily activity as both running and non-running training.

Following this, the main running section of the questionnaire began by asking for participant's total distance ran in the previous week. Individual runs were then accounted for by gathering data for the participant's longest and shortest runs of the week and the corresponding distance, average speed, and maximum speed. Within the individual runs, participants also rated their feelings of motivation, energy, happiness, focus, and effort on a scale of 1-10 to evaluate potential differences in the psychological perception of running.

Data analysis
Software used to analyse the questionnaire output data were IBM SPSS Statistics version 25 and Microsoft Excel version 2110. Descriptive statistics were first calculated to establish mean, standard deviation, and percentage-based population characteristics such as age, BMI, ethnicity and running experience. Next, linear relationships were observed using scatter plots and a Durbin-Watson test to analyse the independence of residuals. A regression analysis was performed to determine the significance of these population variables on the dependent variable (total weekly distance ran). Following this, a Levene's test for equal variance was conducted in preparation for a one-way Welch's ANOVA investigating any differences in lifestyle physical activity (sedentary, light, moderate, and vigorous) in relation to total weekly distance ran. Specific differences were then identified using a Games-Howell post hoc test. Various independent samples T-tests were conducted to test the statistical significance of relationships between targeted caffeine consumption and performance outcomes for both the longest and shortest runs of the week (total distance, average speed, and max speed). Further Levene's tests for equality of variances were conducted prior to running the T-tests to determine the correct significance values to read from the SPSS output. The same tests were repeated for caffeine consumed specifically within an hour prior to these runs as well as for the impact of timed caffeine consumption on perceived moods (motivation, energy, happiness, focus and effort). Finally, a Chi-Square test for association was performed to assess the likelihood of both leisure and competitive runners to use caffeine in a targeted manner to enhance their running experience.

Results
BMI, running experience, and age
Firstly, a linear regression analysis was conducted to evaluate the influence of a series of population variables (age, BMI, and running experience) on total distance covered in a week. Preparing for this, linear relationships were observed using a scatter plot for the independent variables and a Durbin-Watson test result of 1.913 assessed independence of residuals. Inspection of the scatter plots revealed there was also homoscedasticity of the residuals which implies the error is constant. There were few obvious outliers in the data set, those identified in this case were included in the analysis. This is due to the range in running experience levels within the participants, some of whom train for ultra-marathons and so extremely long distances would be justified. The regression analysis showed that BMI is negatively associated with total weekly distance ran, $F(3, 460) = 8.060$, $p = 0.01$. Similarly, running experience was positively associated with greater weekly running distance and was highly statistically significant, $F(3,460) = 8.060$, $p < 0.001$. However, the relationship between age and total weekly running distance was statistically non-significant, $F(3, 460) = 8.060$, $p = 0.451$ ($p > 0.05$).

Influence of physical activity level on total weekly running distance
To better understand any differences between physical activity level and weekly running distance among the participants, a one-way ANOVA was performed. The assumption of homogeneity of variances was violated, as shown by Levene's test for equality of variances ($p < 0.001$). Therefore, a Welch's ANOVA was conducted to investigate equality of the means between different physical activity groups in the study population (sedentary, light, moderate, and vigorous). Total weekly distance

ran was shown in a Welch's ANOVA to be significantly different for different physical activity groups, $F(3, 86.425) = 25.592$, $p < 0.001$. Post hoc analysis was completed using the Games-Howell test as equality of variances had previously been violated. As shown in table 1, those self-reporting vigorous physical activity levels ran significantly further during the week ($p < 0.001$). All other combinations were significantly indifferent apart from between light and moderate, where those who were moderately active, ran a mean 9.05 ± 2.35km further than light activity (p = 0.001).

Table 1: Mean differences in total weekly running distance between vigorously active participants and sedentary, lightly, and moderately active participants.

Physical Activity Level (PAL)	Mean Weekly Distance Ran (km)	Mean Difference (km)	Standard Error	95% Confidence Interval	Significance
Sedentary	31.10	32.26	5.39	[17.97, 46.54]	$p = 0.001$
Light	29.56	33.80	3.93	[23.58, 44.01]	$p = 0.001$
Moderate	38.60	24.75	3.95	[14.47, 35.03]	$p = 0.001$
Vigorous	63.35	N/A	N/A	N/A	N/A

Targeted caffeine consumption around sessions for short and longer runs
An independent samples T-test was conducted to examine the impact of targeted caffeine consumption on distance and speed within shorter and longer runs. The assumption of homogeneity of variances was violated for total weekly distance and distance of the longest run, as assessed by Levene's test for equality of variances ($p < 0.05$). There was a statistically significant difference in mean total weekly running distance between timed caffeine consumers and sporadic consumers, with those timing their caffeine consumption around their runs covering an additional 9.08 ± 2.57km [mean ± standard error] compared to sporadic consumers, $t(425.914) = 3.468$, $p = 0.001$.

When looking at specific running sessions in more detail, there was also a significant difference in the distance of the longest run completed by the participants during the week as shown in table 2. During their longest run of the week, in comparison to random caffeine consumers, timed caffeine consumers completed an extra 2.67 ± 0.85km [mean ± standard error], $t(430.433) = 3.097$, $p = 0.002$. Despite this, no significant differences were observed between the groups for average or maximum speed ($p = 0.948$ and $p = 0.312$). Switching focus to the shortest recorded run of the week, a Levene's test for equality of variances revealed homogeneity of variances for distance, average speed, and maximum speed ($p = 0.173$, $p = 0.706$, and $p = 0.604$ respectively). However, neither of these variables resulted in a statistically significant outcome.

Table 2: Effect of targeted caffeine consumption on participant's longest and shortest runs of the week.

		Targeted caffeine consumption, timed around a running session (yes/no)				
		n	**Mean ± standard error mean**		**Mean difference between groups ± standard error mean**	**Significance**
Longest run	Distance (km)	489	Targeted caffeine	15.53 ± 0.69	2.67 ± 0.85	*p* = 0.002
			Random caffeine	12.86 ± 0.52		
	Average speed (kph)	487	Targeted caffeine	11.56 ± 0.99	-0.11 ± -3.26	*p* = 0.948
			Random caffeine	11.67 ± 1.22		
	Max speed (kph)	483	Targeted caffeine	17.80 ± 6.02	5.58 ± 6.027	*p* = 0.356
			Random caffeine	12.23 ± 0.26		
Shortest run	Distance (km)	480	Targeted caffeine	8.16 ± 0.45	-0.07 ± 0.73	*p* = 0.931
			Random caffeine	8.23 ± 0.57		
	Average speed (kph)	461	Targeted caffeine	7.72 ± 0.19	-0.21 ± 0.26	*p* = 0.406
			Random caffeine	8.14 ± 0.18		
	Max speed (kph)	448	Targeted caffeine	11.43 ± 0.30	0.26 ± 0.39	*p* = 0.512

Effect of targeted caffeine consumption on mood during short and longer runs

Targeted caffeine consumers were then compared with random caffeine consumers by differences in mood during their running sessions. An independent samples T-test was performed using the questionnaire mood scale data to assess differences in perceptions of the recorded running sessions. Again, a Levene's test for equality of variances was performed to test for homogeneity of variances for each mood category in both the longest and shortest run of the week. From the participant data, homogeneity of variances existed for all mood rankings in the longest run ($p>0.05$). However as shown in table 3 below, mean differences between all groups were minor and no statistically significant differences could be observed for changes in mood depending on targeted caffeine consumption ($p>0.05$).

Table 3: Effect of targeted caffeine consumption on mood throughout short and longer runs.

		Targeted caffeine consumption, timed around a running session (yes/no)				
		n	**Mean ± standard error mean**		**Mean difference between groups ± standard error mean**	**Significance**
Longest run	Motivated	486	Targeted caffeine	7.50 ± 0.12	0.13 ± 0.17	$p = 0.458$
			Random caffeine	7.38 ± 0.11		
	Energised	485	Targeted caffeine	7.12 ± 0.12	0.04 ± 0.17	$p = 0.779$
			Random caffeine	7.08 ± 0.14		
	Happy	486	Targeted caffeine	7.60 ± 0.12	0.07 ± 0.17	$p = 0.660$
			Random caffeine	7.52 ± 0.12		
	Focused	484	Targeted caffeine	7.24 ± 0.12	0.02 ± 0.17	$p = 0.880$
			Random caffeine	7.21 ± 0.12		
	Effort	484	Targeted caffeine	6.45 ± 0.13	-0.17 ± 0.18	$p = 0.360$
			Random caffeine	6.62 ± 0.12		
Shortest run	Motivated	486	Targeted caffeine	7.45 ± 0.11	0.04 ± 0.17	$p = 0.811$
			Random caffeine	7.41 ± 0.13		
	Energised	485	Targeted caffeine	7.08 ± 0.12	-0.03 ± 0.17	$p = 0.855$
			Random caffeine	7.11 ± 0.12		
	Happy	486	Targeted caffeine	7.55 ± 0.12	-0.02 ± 0.18	$p = 0.915$
			Random caffeine	7.57 ± 0.13		
	Focused	484	Targeted caffeine	7.24 ± 0.11	0.04 ± 0.17	$p = 0.800$
			Random caffeine	7.20 ± 0.13		
	Effort	484	Targeted caffeine	6.58 ± 0.12	0.09 ± 0.18	$p = 0.636$

Effect of caffeine consumption within an hour before shorter and longer runs

Figure 1a shows the differences in mood reported by the study participants for two groups (those who consumed caffeine in the hour prior to the run and those who did not). During the longest run, mean reported mood for motivated, focused, and effort scores were greater in those who consumed caffeine within an hour before the run. Despite this, there were no statistically significant differences as highlighted by the independent samples T-test (p = 0.811, p = 0.800, and p = 0.636 respectively). Scores for energised and happy were greater in those who did not consume caffeine prior to their run, but these differences were also very minor and statistically insignificant (p = 0.855 and p = 0.915).

Following this, the process was repeated for the participant's shortest run of the week. This time the Levene's test revealed homogeneity of variance for focused and effort data (p = 0.062 and p = 0.635), but violation of homogeneity for motivated, energised, and happy scores (p = 0.046, p = 0.021, and p = 0.031). As shown in figure 1b, differences between groups for motivation, energised and effort scores in the shortest run were found to be statistically significant (p>0.05). Motivation scores were significantly greater in those who consumed caffeine in the hour prior to their shortest run, 0.40 ± 0.20 [mean ± standard error], t(420.719) = 2.007, p = 0.045. The same pattern could be seen for energised scores, 0.51 ± 0.20, t(423.219) = 2.480, p = 0.014, and effort scores, 0.56 ± 0.23, t(461) = 2.429, p = 0.016. Differences could be seen for happy scores, 0.35 ± 0.21, t(429.027) = 1.693, p = 0.091, and focused scores, 0.35 ± 0.22 t(460) = 1.640, p = 0.102, however they were statistically insignificant.

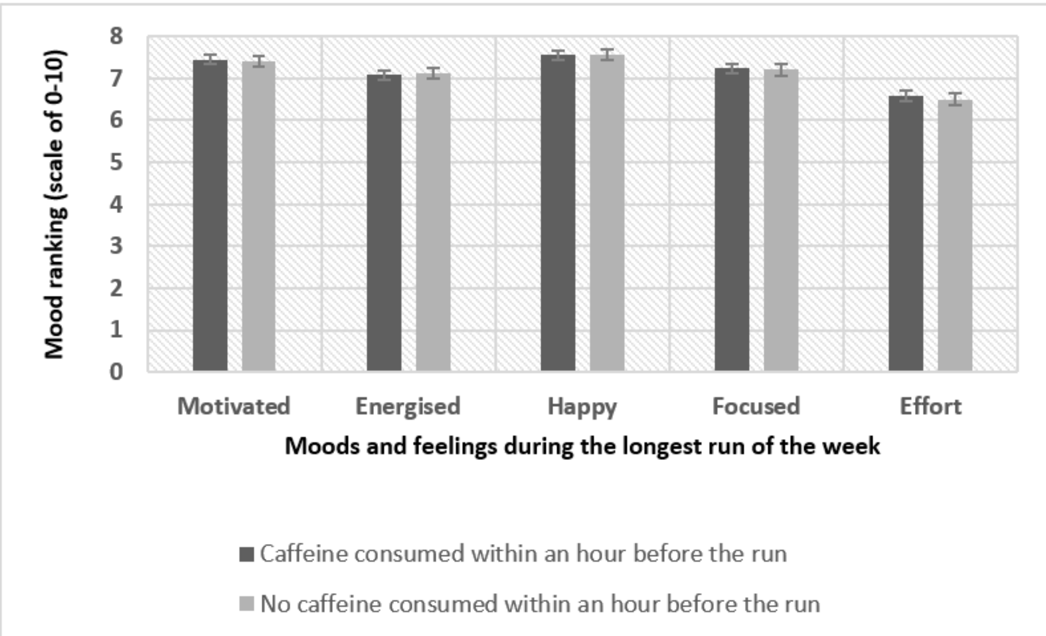

Figure 1a: Changes in perceived mood during the longest run between those consuming caffeine in the hour prior to the run and those who did not.

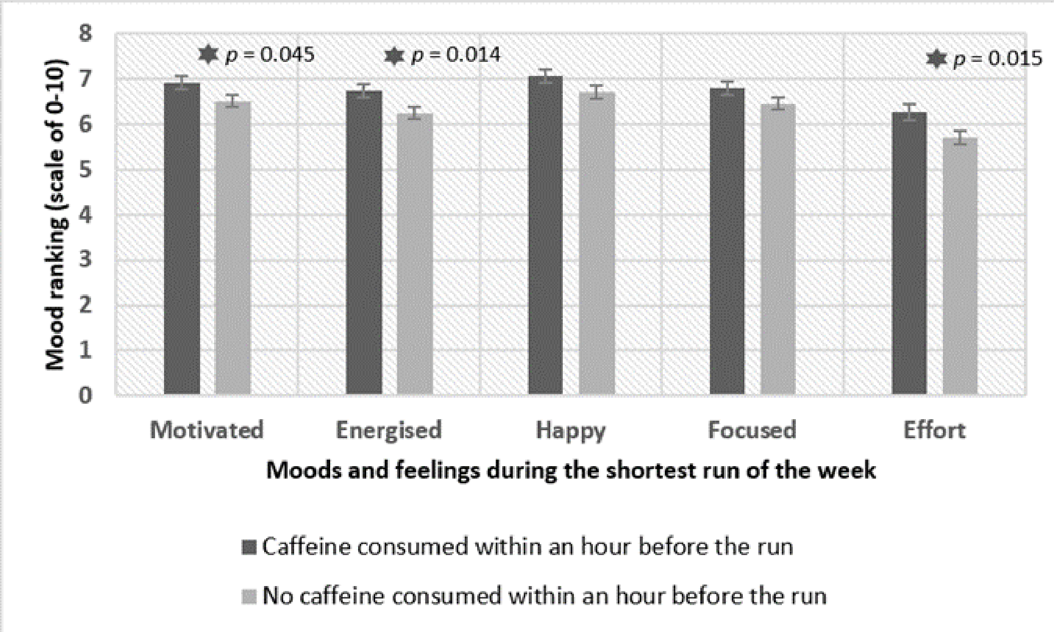

Figure 1b: Changes in perceived mood during the shorter run between those consuming caffeine in the hour prior to the run and those who did not.

Likelihood of targeted caffeine consumption for leisure and competitive runners

A chi-square test for association was conducted between running type (competitive or leisure) and timing of caffeine consumption (random or targeted). All expected cell frequencies were greater than five. 43.0% of participants who ran for leisure were likely to time their caffeine consumption around their sessions in comparison to 52.6% of competitive runners. The *p* value generated is close to the chosen significance level ($p>0.05$) however the difference was statistically insignificant, $\chi^2(1) = 3.638$, $p = 0.056$. Moreover, the likelihood of a strong correlation appeared to be limited given the Phi value -0.086 ($p = 0.056$).

Discussion

The results of the present study support the theory that participating in targeted caffeine consumption can support running endurance by way of increased total weekly distance and distance of longest run during the week. Analysis of the results also suggests that caffeine could be a useful modifiable factor for mood (specifically motivation, perceived energy, and effort) during shorter training sessions. Revisiting the initial aims of the study, caffeine is incredibly versatile as a supplement and is likely to be used differently according to personal goals and exercise experience. The data suggested that competitive runners were 9.6% more likely to time their caffeine consumption around their running training/races. This analysis was close to statistical significance, suggesting there may or may not be a relevant association, however it is useful to remember that fewer beginner runners may currently be accessing these potential benefits to their training. This is especially relevant when considering running experience was positively associated with total weekly distance ran ($p < 0.001$). Logically, this was to be expected given that beginner runners would not start their training journey running marathon-like distances but does support the idea that intermediate to experienced runners are then more likely to turn to supplements, as previously mentioned, to support this additional endurance.

Effects of targeted caffeine consumption on running endurance
In agreeance with the hypothesis, participants of the current study demonstrated significantly greater total distance in those that targeted their consumption around their running sessions in comparison to sporadic consumers. Timed consumers completed a mean additional 9.08 ± 2.57km over the week-long period (p=0.001). If training for a longer distance race such as a half marathon, an almost additional 10km per week (approximately half the distance of a half marathon) provides substantial extra practice time. Thus, allowing the runner additional scope to work on technique and to run at distances closer to the target distance of a race. Similarly, when looking at the specific data provided for the longest run, prior caffeine consumption resulted in an additional 2.67 ± 0.85km distance completed (p = 0.002). These findings oppose those suggested by Candow *et al* (2009), who completed a time to exhaustion test among active young adults, using sugar free Red Bull energy drinks as a caffeine source and a placebo. Time to exhaustion did not differ significantly between the two conditions (Red Bull: 12.6 ± 3.8 minutes, placebo: 11.8 ± 3.4 minutes, p>0.05). Plausible explanations for these results include the relatively low dose of caffeine provided ($2mg{\cdot}kg^{-1}$ body weight) in comparison to studies of similar intensities who used up to $6mg{\cdot}kg^{-1}$ body weight and saw significant improvements in endurance (Graham and Spriet, 1985). In the present study, there were also no significant differences observed in distance within the shortest run according to caffeine consumption (p = 0.173). It is likely that higher intensity exercise, such as running, would benefit from greater quantities of supplementation before a noticeable difference in endurance could be observed.

Another important consideration for the ergogenic use of caffeine in endurance is the frequency to which subjects habitually consume caffeine in their daily lives. Bell and McLellan (2002) found that subjects who do not regularly consume caffeine in their leisure time saw greater ergogenic effects in endurance (time to exhaustion at 80% $VO2_{max}$). Results of the study suggested that $5mg{\cdot}kg^{-1}$ body weight generated increased exercise duration among those who do not often consume caffeine (non-users: 32.7 ± 8.4, caffeine users: 27.4 ± 7.2, p<0.05). From a competitive running perspective, it might be appropriate to implement a reduced caffeine intake day to day to see maximal benefits of increased caffeine load on race day. This evidence is supported by Flinn *et al* (1990), who concluded that irregular caffeine consuming cyclists had increased time to exhaustion when provided with a $10mg{\cdot}kg^{-1}$ dose of caffeine. However, this dose was notably higher than other similar studies, each with differing conclusions and leaving a need for further research within populations of caffeine and non-caffeine users (Butts and Crowell 1985; Sasaki *et al* 1987). With elevated doses of caffeine in an unaccustomed population, there are also risks of side effects such as palpitations and post consumption fatigue which would be unhelpful to race performance and should be considered Lee *et al* (2009).

Effects of targeted caffeine consumption on running speed

Findings for speed performance in the current study showed that targeted caffeine consumption had no effect on average or maximum speed in the longest run of the week ($p>0.05$). However, there are examples of cases where caffeine has significantly decreased the time taken to run a given distance. Bridge and Jones (2006) aimed to investigate the impact of caffeine consumption of 3mg/kg body weight on 8km distance runners. Like the present study, caffeine was ingested 60 minutes before the exercise, which resulted in an 8km time 23.8 seconds faster than with the placebo (95% CI = 13.1 to 35.4 seconds, $p<0.05$). Whilst this may not seem like it would alter the outcome of a race, for elite competitive runners, this 1.2% performance improvement may be the difference between podium positions where competitors are very similar in level such as Olympic events (Christensen *et al*, 2017). Similarly, Prins *et al* (2016) found that ingestion of a Red Bull energy drink led to around 2.1% faster 5km running times compared to the placebo ($p=0.016$). Although, it is worth remembering that the study was conducted within a population of recreational endurance runners and that results could differ significantly from a competitive of mixed running group.

Likewise, the present study showed no significant difference in any of the speed variables for the shortest run of the week ($p>0.05$). These results fit with the findings of Astorino *et al* (2011), who analysed the effect of consuming 255ml of Red Bull energy drink or a placebo on sprinting speed. Red Bull and placebo sprinting times showed no significant differences (Red Bull: 11.31 ± 0.61 seconds, Placebo: 11.35 ± 0.61 seconds, $p>0.05$). Despite this, each drink of Red Bull contained just $1.3mg \cdot kg^{-1}$ body weight, which is much smaller than caffeine doses used in longer runs investigated by the likes of Bridge and Jones (2006). It is possible that the dose provided was too small to elicit a significant effect. According to a meta-analysis by Christensen *et al* (2017), there was a significant improvement in running speed within events lasting between 45 seconds and 8 minutes when supplemented with caffeine. However, it is noted that the effect size is relatively small (0.41km/h, 95% CI: 0.15-0.68, $p=0.002$). Consequently, the results of the present study in conjunction with previous research emphasise the need for additional study surrounding reduced ergogenic effect of caffeine for shorter exercise events and specific interaction on an individual level.

Effects of targeted caffeine consumption on perceived mood during running

In this study, the effect of targeted caffeine consumption appeared to be mixed. When asked whether they time caffeine consumption around their running sessions, participants showed no differences in mood during shorter and longer runs ($p>0.05$). It is possible that the lack of differences could be attributed to the vague nature of question which gave no indication of subject's timeframe of consumption. Interestingly, once asked specifically whether caffeine is consumed within an hour prior to a shorter run, participants demonstrated increases in motivation (0.40 ± 0.20), energised (0.51 ± 0.20), and effort (0.56 ± 0.23) scores. This provides a new insight into the specific moods experienced by runners because of caffeine consumption, which adds to the existing plethora of studies focusing on just perceived effort. One study by Duncan *et al* (2012) looked at caffeine's effect on mood state as well as readiness to invest effort within a population of 13 resistance-trained men. Similarly, to the current study, the impact of ingesting 179mg caffeine

60 minutes prior to exercise was studied with the resulting ratings of perceived effort (RPE). Results revealed consumption of caffeine an hour before exercise led to greater reductions of RPE in comparison to the placebo (mean difference = -0.538, $p = 0.022$). Although this study was based on resistance training, others have reported similar findings for aerobic exercises like running. Doherty *et al* (2005) found that in high intensity cycling training perceived effort was reduced in those who consumed 5mg of caffeine per kg body weight by roughly one RPE increment ($p<0.05$). This supports the idea that shorter, intense durations of aerobic exercise may benefit from caffeine supplementation to reduce perceived effort, leaving runners to feel as though they have the capacity to further increase their exercise output and improve performance. The same authors also conducted a meta-analysis of 21 studies where caffeine was found to reduce mean exercise RPE by 5.6% (95% CI, -4.5 to -6.7%) which further confirms this point (Doherty and Smith, 2005). However, a regression analysis in this study suggested that only ~29% of exercise performance improvement was likely to be due to reduced RPE. Whilst being a useful tool to improve performance, runners shouldn't solely rely on reduction of perceived effort and should ensure they cover all other potential areas such as diet and technique.

Although results of the present study suggest improvements to mood were only visible in shorter runs, there are other studies which equally present benefits for distance running. Birnbaum and Herbst (2004) conducted a double-blind trial with 10 cross country runners (5 male and 5 female) where participants completed two 30-minute runs on the treadmill at 70% $VO2_{max}$. Before one run participants consumed 7 $mg \cdot kg^{-1}$ body weight of caffeine or a vitamin C based placebo. Results from the study suggest that RPE was reduced by with consumption of caffeine in comparison to the placebo (caffeine: 10.8 ± 1.5, placebo: 11.2 ± 1.7, $p = 0.037$). However, RPE is typically given as an integer, when rounded to the nearest whole number both conditions display an RPE of 11, which suggests that despite statistical significance, practical differences may not be great enough to see a useful effect. These conclusions are supported by the findings of Casal and Leon (1985) where after 45 minutes of running at 75% $VO2_{max,}$ RPE was significantly lower under the caffeine condition compared to the control (caffeine: 12.0 ± 0.6, control: 13.8 ± 0.5, $p<0.05$). Despite this, there was a chance of the placebo effect occurring in the study since consuming both caffeinated and decaffeinated coffee (<50mg) induced reductions of RPE. Further research would be beneficial to compare the psychological effects of caffeinated and decaffeinated coffee with a different source of caffeine to confirm whether the experience of consuming a particular food or beverage is partly responsible for determining an individual's RPE. Consequently, discovering whether a non-caffeinated, coffee flavoured placebo would elicit a similar response in runners without the need to rely on a drug for performance should restrictions on use be reintroduced.

Strengths and limitations

One of the key strengths of study is its large sample size. With online access to the survey, the opportunity for global reach was opened. Initially, the study aimed to reach approximately 100 participants, but after success within online running forums word quickly spread into the wider community. As a result, the questionnaire was able to reach countries outside the United Kingdom, with large numbers amassed from the United States of America (309 participants). As a result, the study was able to be more representative of the wider population than if a small selection of local participants were recruited. Although participants were mostly white Caucasian (89%) and showed minimal ethnic diversity, it is likely this value would have been even higher had the study not encapsulated 26 other countries.

However, with a large sample size also came some limitations. It was beyond the scope of the study to address differences in dose of caffeine consumed. Initially the questionnaire gathered data on specific types of caffeinated beverages and products with the aim of collecting information for as many different brands and caffeine sources as possible. Since it was never anticipated that the survey reach would extend past the United Kingdom, the survey was underprepared for a global audience whose products are different in nutritional composition. It was no longer possible to accurately analyse the output as intended as even the same coffee shop chains differ in caffeine content depending on the country. Consequently, the study is limited by the lack of dose information for the associations observed and further research is required to establish whether dose of caffeine impacts running performance and endurance when timed consumption is in place.

Additionally, participants were required to recall their caffeine consumption and mood data from the week prior to completing the survey. As with most examples of dietary recall, there are limitations to the accuracy of memory participants have when reporting past events. Intake can vary significantly between reported and actual intake. In some studies, differences in nutrients have been observed of up to 400%, thus increasing the likelihood of reporting errors and inaccuracies to the overall study results (Bingham, 1991). If given the opportunity to extend the budget of the study, it might be appropriate to conduct further research using observation and weighed intake of caffeine as well as other dietary components to allow for more accurate participant analysis. This lab-based approach would allow deeper analysis of other dietary components as potential confounding factors as well as ensure a more accurate analysis of caffeine dose can be performed. Furthermore, additional studies could incorporate the use of biomarkers to validate the dietary intake reported by a questionnaire. With a longer time frame and greater budget, more precise methods of validation could be considered, such as the doubly labelled water technique to validate energy intake, as well as measurement of blood plasma caffeine concentration by spectrophotometry or chromatography (Bingham, 1987; Pearson *et al*, 1984).

Conclusions

This study aimed to determine how targeted and sporadic consumption of caffeine as a supplement may have an impact on the speed, endurance, and mood of both competitive and recreational adult runners. While caffeine is one of the most recognised recreational drugs and ergogenic aids, runners and other athletes are yet to experience the true potential of its sporting benefits, particularly when consumed in a targeted manner or in an individual who is not a habitual caffeine user. It can be said that caffeine is indeed a useful ergogenic tool to assist runners wishing to cover greater distances in their endurance training sessions and races. In answer to the research question, caffeine also has the potential to assist runners, predominantly in shorter, high intensity sessions with their motivation, as well as remaining energy and effort to push their progress nearing exhaustion. Although not proven to be significant in this study, evidence (despite being small in effect size) is also emerging for potential advantages to speed because of caffeine. Supplements for sports performance can be costly, and for recreational runners often unattainable. As a widely available, relatively inexpensive recreational drug, caffeine offers new potential for beginner athletes to see improvements in their performance. The present study clearly demonstrates the potential of caffeine supplementation, but also raises questions surrounding cyclic supplementation, where the drug is only used prior to competition to enhance the strength of the effect. To assess the plausibility of this method, further research could be considered with a focus on periodisation, and in turn enhance running performance.

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