

Effects of a Caffeine-Containing Transdermal Energy Patch on Aerobic and Anaerobic Exercise Performance

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ABSTRACT

Int J Exerc Sci 4(2): 141-151, 2011. The use of caffeine-containing (74-mg) energy patches (EnP) offers a novel mode of caffeine delivery that may alleviate stomach discomfort associated with oral caffeine use. The purpose of this study was to use four separate tests to evaluate the effects of EnP use on aerobic and anaerobic exercise performance. Three separate moderately active college-aged sample populations performed either 1) cycle time-to-exhaustion (n = 9), 2) Wingate (WIN; n = 13), or 3) repeated sprints and one repetition maximum bench press (n = 10) using EnP and placebo patches (PIP). No statistical differences were found between EnP and PIP for all dependent variables ($p > 0.05$) except for WIN peak power, which showed a statistically significant decrease ($p = 0.04$). The dose of caffeine topically applied via an EnP may not have been enough to elicit an ergogenic effect on exercise performance. A dose of caffeine greater than 74-mg may be needed to produce an ergogenic effect. Further research is needed to investigate the delivery kinetics of transdermal caffeine in large dosages along with blood caffeine concentrations during and after exercise.

KEY WORDS: Caffeine, transdermal, aerobic, cycling, Wingate, sprint

INTRODUCTION

The effects of orally ingested caffeine on exercise performance have been well documented since Costill et al. (10) initially proposed caffeine's ergogenic effect on endurance cycling. Caffeine has shown obvious increases in laboratory-based endurance tests. Graham and Spriet (14) showed increases of 44.3 and 52.3% for elapsed time at exhaustion (ET) for run and cycle time-to-exhaustion (TTE) tests at 80% maximal oxygen consumption (VO_{2MAX}),

respectively, in well-trained distance runners who consumed 9-mg/kg body weight (BW) caffeine orally 60-min prior to testing. Similarly, 6-mg/kg BW caffeine increased ET in a sample of healthy active males by 22% at 80-85% VO_{2MAX} when orally ingested 90-min before testing (15). Other studies have shown increases in ET by 19.5% (10), 26.9-30.0% (27), and 27% (25). In contrast, Hendrix et al. (19) found that a caffeine-containing supplement with 400-mg (~5-mg/kg BW) caffeine, 66.7-mg capsicum extract, 10-mg bioperine, and 40-

mg niacin elicited no statistical improvement for ET. Unlike the aforementioned studies, the authors used an untrained sample and a cycle TTE intensity that corresponded to 80% power output of max power elicited at VO_{2MAX} (W_{MAX}). In a different sample of untrained participants, 5-mg/kg BW caffeine was orally ingested 60-min prior to cycle TTE at 10% W_{MAX} above and below anaerobic threshold (11). A statistical increase in performance was seen below the anaerobic threshold while no difference was seen above the anaerobic threshold for ET. Accordingly, no improvement found by Hendrix et al. (19) may be due to an increased reliance on anaerobic energy systems elicited by the TTE test's high intensity relative to an untrained population.

Unlike endurance tests, caffeine has shown no evidence supporting an ergogenic effect for the 30-s Wingate (WIN) test between caffeine and placebo conditions. No statistical differences for peak power (PP) have been seen in resistance-trained men (3), recreationally active men (16,17,22), healthy men (6), or healthy men and women (9). Mean power (MP) and fatigue index (FI) were not significantly different in recreationally active men (16,17,22). Similarly, MP was not significantly different in resistance trained men (3). Notably, the aforementioned studies used flywheel resistances of 0.075-0.090-kg/kg BW and varied caffeine dosages (~2.4-mg/kg BW to 6-mg/kg BW).

Repeated-sprint (RS) performance in single and multiple sets has apparently benefitted from caffeine use as measured by several dependent variables, including total sprint (TS) and mean sprint (MS) times for a given

set of sprints, fastest sprint (FS), and the difference between initial and final sprints (ΔIF). Carr et al. (8) showed statistically decreased TS when 6-mg/kg BW caffeine was orally ingested 60-min prior to 5-sets of 6-reps of 20-m sprints repeated at 25-s (sets 1, 3, and 5) or 60-s (sets 2 and 4) intervals. Similarly, Glaister et al. (13) showed decreased FS time by 0.06 ± 0.05 -s for 12-reps of 30-m sprints repeated at 35-s intervals with 5-mg/kg BW caffeine. Contradictory to these results, 6-mg/kg BW caffeine appeared to have no effect on MS (0.1% [-1.7-1.5%]) and ΔIF (0.7% [-1.8-3.2%]) for 10-reps of 20-m sprints at 10-s intervals (26). It should be noted that the improvements seen by Carr et al. (8) and Glaister et al. (13) may be attributed to longer rest intervals of 20-55-s between repetitions as opposed to the ~6-s rest intervals utilized by Paton et al. (26).

Beck et al. (3) reported a statistically significant 2.1% increase in one repetition maximum (1-RM) bench press (BP) in 37 resistance trained men following ingestion of a caffeine-containing supplement 60-min prior to testing. The supplement consisted of 201-mg caffeine, vitamin C and B6, niacin, pantothenic acid, and a variety of caffeine containing extracts. More recently, no significant difference was found between the same caffeine-containing supplement and placebo in untrained men for 1-RM BP (2). This contradicted their previous study leading the authors to conclude that untrained participants may not receive the ergogenic effect of the caffeine-containing supplement while those in a trained state may. Additionally, the latter finding is in line with recent reports of unaffected 1-RM BP in resistance trained (1) and untrained (19) men after oral consumption of 6-mg/kg BW and 400-mg

(~5-mg/kg BW) caffeine, respectively. Also, statistically insignificant differences between oral caffeine and placebo conditions were found for 1-RM leg extension (3,19) and leg press (1).

Side Effects of Orally Ingested Caffeine

Caffeine reportedly elicits an array of positive and negative side effects. In a well written review, Fredholm et al. (12) stated that positive side effects of caffeine include participants claiming to be more active, attentive, and less fatigued. Negative side effects include jitters, nervousness, anxiety (12), dizziness, headaches, muscle tremors, hunger sensations, insomnia, diuresis (25), and nausea (15). Astorino et al. (1) found that 60% of participants reported negative side effects of tremor, insomnia, increased heart rate, and restlessness when a caffeine condition of 6-mg/kg BW caffeine orally ingested 60-min prior to exercise was received in opposition to a placebo condition. The authors reported that these effects were more common in non-habitual caffeine users than habitual caffeine users and is in agreement with the review of Fredholm et al. Fredholm et al. stated that non-habitual caffeine users may experience negative side effects of caffeine at all dosages, while habitual caffeine users typically experience negative side effects at large dosages. Two of eight participants complained of nausea after oral ingestion of 6-mg/kg BW caffeine (15). This supports the data of Hudson et al. (20), who found that stomach distress, accompanied by restlessness and tremors, was statistically higher in the 6-mg/kg BW caffeine than placebo condition. The aforementioned studies used 300-mg (4-mg/kg BW for a 75-kg participant) to 6-mg/kg BW oral caffeine with stomach discomfort occurring in the latter dose. The latter dose was within the

5-9-mg/kg BW caffeine range needed to produce an ergogenic effect for cycle TTE and RS. Therefore, taking oral caffeine to improve exercise performance (i.e. large dosages) may lead to undesirable stomach discomfort in both non-habitual and habitual users.

Transdermal Application

Studies have investigated transdermal kinetics of caffeine; however, no studies to our knowledge have done so solely with large quantities of caffeine, i.e. 75-mg caffeine applied topically. Heard et al. (18) conducted an *in vitro* study of permeation of the caffeine containing extract guarana using full thickness porcine ear skin in accordance with the work of Meyer et al. (23). The authors showed that increasing the amount of topically applied guarana extract, containing 2.1-6.0% caffeine, within a transdermal patch linearly increased ($r^2 = 0.978$) the rate of caffeine permeation. This suggests that transdermal delivery of caffeine may have a dose-response relationship, possibly due to an altered electrochemical gradient. When 10- μ g caffeine was applied to a skin surface area of 25-cm², Otberg et al. (24) found that caffeine permeated the skin within 5-min and reached maximum plasma concentrations of 11.75-ng/mL at 60-min *in vivo*. The plasma caffeine concentration of 11.75-ng/mL for topically applied caffeine was much less than the plasma caffeine concentrations of 5.09-6.39- μ g/mL (5) and 6.85- μ g/mL (21) shown to elicit an ergogenic effect for cycle TTE (4-6-mg/kg BW caffeine orally administered 60-90-min prior to analysis). With a linear increase of plasma caffeine concentrations with increasing topically applied caffeine, a dosage three magnitudes greater (i.e. mg of caffeine) has a potential to produce plasma

concentrations three magnitudes greater (i.e. $\mu\text{g/mL}$ caffeine). Therefore, a relatively large dose of topically applied caffeine 60-min prior to exercise may be effective in delivering the quantity of caffeine necessary for an ergogenic effect to take place.

The introduction of a caffeine-containing energy patch (EnP) may represent an option to supplement with caffeine to improve exercise performance while potentially avoiding the negative side effect of stomach discomfort associated with orally ingested caffeine. Therefore, the purpose of this study was to investigate the effects of a caffeine-containing transdermal EnP on exercise performance in four well-documented tests.

METHODS

Participants

Three separate voluntary sample populations (see Table 1) were used to determine the effectiveness of EnP use on 1) cycle TTE, 2) WIN, and 3) RS and 1-RM BP. Prior to recruitment, the study was approved by Eastern Washington University's Institutional Review Board. All participants were provided written and verbal instructions 48-h prior to testing and gave written consent. Selection criterion required participants to be between the ages of 18 and 35-y and moderately active (i.e. 30-min of moderate intensity exercise 3-5-d/wk). Participants completed a standard AHA/ACSM preparticipation screening questionnaire to assess several risk factors. Individuals with zero or one risk factor were allowed to participate in the present study. Individuals with two risk factors were referred to a physician for clearance. Individuals with three or more

risk factors were not allowed to participate in the study. Participants filled out a caffeine questionnaire to determine daily habitual caffeine use.

Table 1. Participant demographics and daily habitual caffeine use for the three samples.

Sample		Age (y)	Height (m)	Weight (kg)	Caffeine Use (mg/d)
Cycle TTE	n = 9	25 ± 4.7	1.74 ± 0.09	74.7 ± 18.7	171.6 ± 163.7
WIN	n = 13	22 ± 3.4	1.76 ± 0.06	89.5 ± 23.3	93.4 ± 146.8
RS and 1-RM BP	n = 10	23 ± 5.0	1.71 ± 0.06	73.6 ± 10.2	179.5 ± 190.3

Values are presented as mean ± standard deviation. TTE = time-to-exhaustion, WIN = Wingate, RS = repeated-sprints, 1-RM = one repetition maximum, BP = bench press.

Protocol

The pre-experimental procedures were identical for each test. Prior to arrival, all participants were asked to refrain from strenuous exercise, obtain a restful night's sleep, remain well hydrated, and eat a regular meal. Furthermore, participants were provided a list of caffeine-containing food stuffs and were told to refrain from caffeine consumption 48-h prior to testing. Upon arrival of the participants' first session height, weight, and age were collected. A minimum of 48-h separated each test session. All participants underwent two tests, one with two EnP (Enceutical Corp., Addison, Texas) and one with two placebo patches (PIP). Each EnP contained 37-mg caffeine, 5- \square g taurine, 5- \square g glucuronolactone, 4-mg green tea extract, 2-mg of both vitamin B3 and B5, and 800- \square g of both vitamin B6 and B12 with a surface area of 14.5-cm². The amount of caffeine delivered topically with the EnP is reported in Table 2. The PIP were previously exhausted EnP with spray adhesive applied.

Table 2. Absolute and relative caffeine dosages for the three samples.

Sample	Caffeine (mg)	Caffeine (mg/kg)	Caffeine (mg/cm ²)	Caffeine (mg/kg/cm ²)
Cycle TTE	74.0	1.030 ± 0.178	2.55	0.0355 ± 0.0061
WIN	74.0	0.883 ± 0.225	2.55	0.0304 ± 0.0077
RS and 1-RM BP	74.0	1.022 ± 0.129	2.55	0.0352 ± 0.0044

Values expressed as mean ± standard deviation. TTE = time-to-exhaustion, WIN = Wingate, RS = repeated-sprints, 1-RM = one repetition maximum, BP = bench press. Caffeine dose is represented as an absolute value (mg) and relative to BW (mg/kg), surface area of the patch (mg/cm²), and both BW and surface area (mg/kg/cm²).

Cycle TTE Experimental Procedures

The cycle TTE tests were completed in four sessions. For each cycle test, participants warmed up at a self-selected workload and duration and were required to maintain a pedal cadence of 60-65-rpm. Seat height was recorded and used for each successive cycle test. Session one consisted of an incremental workload test on a Monark 328e cycle ergometer (Monark, Stockholm, Sweden) to determine relative $\dot{V}O_{2MAX}$ ($r\dot{V}O_{2MAX}$). For the first half of session two, the workload associated with 80% of $r\dot{V}O_{2MAX}$ was verified with an Oxycon Pro mobile metabolic cart (CareFusion, San Diego, CA) during approximately 5-min of cycling. The second half of session two was devoted to test familiarization. Participants were instructed to cycle to volitional exhaustion at the workload associated with 80% of $r\dot{V}O_{2MAX}$ using a cadence of 60-65-rev/min. If the cadence fell below 60-rev/min, the participant received verbal encouragement to increase their cadence. When cadence fell below 60-rev/min for

five continuous seconds, the test was terminated and the time in seconds was recorded. Sessions three and four were the experimental TTE tests. Two EnP or PIP were randomly assigned in a single-blinded, crossover design for session three; session four received the opposite condition. The patches were applied directly to the skin, proximal to the medial aspect of the belly of the right biceps brachii. Following receipt of the EnP or PIP, participants rested for 60-min to allow for caffeine absorption. During this time, no food, drinks, or other ergogenic aids were allowed except water as requested. The cycle TTE tests then commenced and were identical to the familiarization cycle TTE procedures. In addition, participants were blinded to all display feedback except cadence. Time at exhaustion was recorded for data analysis.

Wingate Experimental Procedures

The WIN test is a 30-s maximal effort cycle ergometer test designed to assess anaerobic work capacity of an individual. The WIN tests were completed in three sessions. For each WIN test, participants warmed up at a self-selected workload and duration. All tests were conducted on a Monark 894e cycle ergometer (Monark, Stockholm, Sweden). Seat height was fitted to the participants' comfort, recorded, and used for all successive WIN tests. Session one was dedicated to familiarization. Participants performed a WIN with a resistance equivalent to 0.075-kg/kg BW and received strong verbal encouragement for the entire 30-s. Sessions two and three were the experimental WIN tests. Two EnP or PIP were randomly assigned in a single-blinded, crossover design for session two; session three received the opposite condition. The patches were applied

directly to the skin as previously described. Participants then rested for 60-min to allow for absorption. During this time, no food, drinks, or other ergogenic aids were allowed except water *ad libitum*. After the rest period, the WIN tests were performed. Mean power, PP, and FI were recorded for data analysis.

One-RM and RS Experimental Procedures

One-RM and RS were tested over a three session period. A standard Olympic barbell, weights, and bench were used for BP testing. The first session was a familiarization session. Participants performed a BP warm-up that consisted of 2-3-sets of 3-10-reps of increasing resistance. Participants then attempted their estimated 1-RM BP weight. If participants successfully lifted the weight, 2-5-min rest was allotted and additional weight was added. If the attempt was unsuccessful, rest was given and the weight was reduced. In both cases, participants performed multiple 1-RM attempts until an accurate 1-RM was determined. Following the 1-RM BP test, participants relocated to an indoor 200-m synthetic track to perform the RS familiarization test. Participants performed a warm-up including assigned and self-selected components followed by 6-reps of 20-y sprints with 30-s rest. Participants were told to complete each sprint at an all out maximal effort. Sprint time was recorded using a wireless timing gate system (TC system, Brower Timing Systems, Draper, UT). Sessions two and three were the experimental RS and 1-RM BP tests. Two EnP or PP were randomly assigned in a single-blinded, crossover design for session two; session three received the opposite condition. The patches were applied directly to the skin in the aforementioned manner. Participants

then rested for 60-min to allow for caffeine absorption. During this time, no food, drinks, or other ergogenic aids were allowed except water *ad libitum*. The weight pressed (WP) during the 1-RM BP and sprint times were recorded for data analysis.

Statistical Analysis

Paired *t*-tests were used to determine significant differences ($p \leq 0.05$) between EnP and PIP conditions for ET (cycle TTE test), MP, PP, and FI (WIN test), MS and FS (RS test), and WP (1-RM BP test). A two-way repeated measures (condition \times sprint) ANOVA was used to determine significant differences ($p \leq 0.05$) between each of the six sprints for RS tests. Final sprint subtracted from the initial sprint determined Δ IF scores. The difference between conditions ($p \leq 0.05$) for Δ IF was determined using a paired *t*-test. Lastly, to determine if there was a learning effect during testing for each exercise condition, the first and second tests were compared using *t*-tests for each of the aforementioned dependent variables.

RESULTS

There was no statistical difference ($p = 0.25$) between EnP and PIP ET despite there being a shorter ET in the EnP condition than the PIP condition (1627.4 ± 784.1 -s v. 2037.0 ± 1328.0 -s, respectively). Also, no learning effect (first test = 1769.7 ± 814.1 -s, second test = 1810.3 ± 1363.6 -s, $p = 0.91$) was observed.

Wingate results are presented in Table 3. Mean power for the EnP was less than the PIP, but was not statistically different ($p = 0.4$). The EnP was significantly less than the PIP for peak power by 3.00% ($p = 0.04$), or 23.1-W. Additionally, EnP FI was less

than PIP FI; however, no statistical difference was found ($p = 0.1$). Furthermore, no learning effect was observed for MP (first test = 574.0 ± 184.2 -W, second test = 575.8 -W ± 183.9 , $p = 0.77$), PP (first test = 760.4 ± 251.1 -W, second test = 760.7 ± 257.7 -W, $p = 0.98$), or FI (first test = $41.5 \pm 7.1\%$, second test = $42.8 \pm 7.2\%$, $p = 0.54$).

Table 3. Power and fatigue results for the Wingate test.

	MP (W)	PP (W) *	FI (%)
EnP	572.5 ± 187.8	749.0 ± 256.1	40.5 ± 8.9
PIP	577.2 ± 180.1	772.2 ± 252.1	43.8 ± 4.2

Values are represented as mean \pm standard deviation. EnP = energy patch, PIP = placebo patch, MP = mean power, PP = peak power, FI = fatigue index. * indicates significant difference between EnP and PIP conditions.

No differences were seen between individual sprints ($p > 0.05$; see Figure 1). Mean sprint ($p = 0.73$), FS ($p = 0.39$), and Δ IF ($p = 0.68$) times were similar between EnP and PIP conditions (see Table 4). Furthermore, no learning effects were observed between individual sprints ($p > 0.05$), MS (first test = 3.74 ± 1.08 -s, second test = 3.75 ± 1.08 -s, $p = 0.76$), FS (first test = 3.66 ± 0.28 -s, second test = 3.67 ± 0.32 , $p = 0.80$), and Δ IF (first test = 0.023 ± 0.104 -s, second test = 0.035 ± 0.081 -s, $p = 0.79$).

DISCUSSION

The present study was novel because it was the first to investigate a topically applied EnP on aerobic and anaerobic performance. The EnP elicited no beneficial effects for any measured dependent variable for cycle TTE, WIN, RS, or 1-RM BP. More than anything else, these results may be attributed to the caffeine dosage used. We

are inclined to believe that the topically applied dose of caffeine was too low to elucidate an ergogenic effect based on what has been previously reported in studies that administered caffeine orally. However, it is difficult to compare the present results with those seen in previous studies because topically applied caffeine has different delivery kinetics than oral caffeine. Therefore, despite the fact that the EnP caffeine dosages were less than those reported for orally ingested caffeine, the dosages cannot be directly compared.

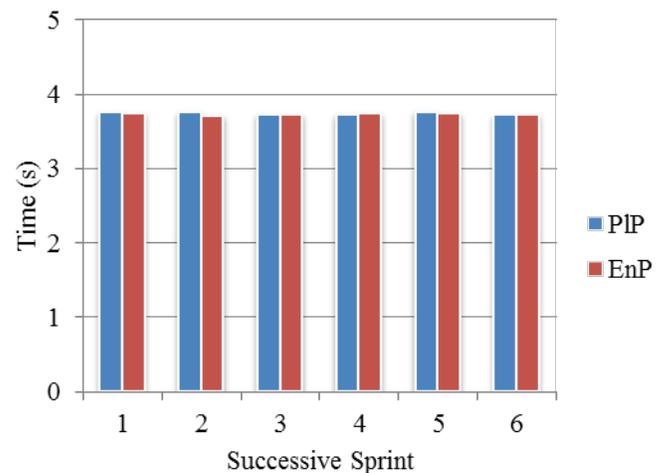


Figure 1. Repeated sprint times showed no differences between conditions or successive sprints. PIP = placebo patch, EnP = energy patch.

Table 4. Sprint and fatigue results for the repeated-sprint test.

	MS (s)	FS (s)	Δ IF (s)
EnP	3.74 ± 0.31	3.65 ± 0.31	0.020 ± 0.078
PIP	3.75 ± 0.28	3.68 ± 0.29	0.038 ± 0.106

Values are represented as mean \pm standard deviation. EnP = energy patch, PIP = placebo patch, MS = mean sprint, FS = fastest sprint, Δ IF = difference between initial and final sprints.

One-RM BP

The present study observed no difference between conditions for 1-RM BP, which was expected based upon previous research (1,2,19).

Wingate

The WIN showed no significant differences for MP and FI across EnP and PIP conditions. This is consistent with the literature for oral caffeine dosages of ~2.4-6-mg/kg BW (2,3,9,16,22). The EnP resulted in a significant decrease of 3.00% in PP despite the absence of a learning effect. This is in contrast to the aforementioned studies that showed no difference between caffeine and placebo conditions. However, the significant difference observed in PP is likely a Type II error due to a low observed statistical power (0.035) associated with small sample size ($n = 13$) and small effect size ($d = 0.09$).

Repeated-Sprints

Repeated-sprints showed no difference between any of the measured dependent variables. The results of the present study disagreed with Carr et al. (8) and Glaister et al. (13) for MS and FS and agreed with Paton et al. (26) for FS and Δ IF. The present study gave 30-s rest between sprints. Methodologically, this was more similar to Carr et al. (8) and Glaister et al. (13) who utilized ~20-55-s and dissimilar to Paton who gave ~6-s rest between sprints. Consequently, we believe this supports the assertion that too little caffeine was used in the present study. If too little caffeine was used, plasma caffeine concentration levels would not have been elevated sufficiently to elicit an ergogenic effect. Therefore, the 74-mg dose of topically applied caffeine appeared to be equivalent to an orally-ingested dose less than 5-mg/kg BW.

Cycle TTE

Exhaustion time showed no difference between EnP and PIP conditions. Previous research has shown ET to increase with oral caffeine doses of 5-9-mg/kg BW. As aforementioned, the lack of an ergogenic effect in the present study suggested that the 74-mg topical caffeine dose was equivalent to an oral dose less than 5-9-mg/kg BW. Furthermore, oral caffeine doses as low as 2-3-mg/kg BW have been shown to improve endurance performance while doses below 2-mg/kg BW have shown no effect (7). In this case, the equivalent EnP caffeine dose may have even been less than the observed lower limits of 2-3-mg/kg BW.

Statistical Considerations

A subject in the cycle TTE test may have been an outlier. This subject had a PIP ET of 5237-s and an EnP ET of 2938-s. Furthermore, EnP preceded PIP in test order. When the t -test was recalculated omitting subject A, there was a greater probability that the EnP had no effect on ET ($p = 0.53$). In addition to a possible outlier, the sample sizes of the three samples were less than or equal to 13. These small sample sizes may have lowered the statistical power. Therefore, in addition to a small topically applied caffeine dosage, the results of the study may have been compromised by a combination of small sample sizes, low effect sizes, and/or low statistical power.

Continual Caffeine Delivery

Despite the lack of observed ergogenic effects in this study, one possible advantage of an EnP would be the continual administration of caffeine. An oral dose of 5-mg/kg BW caffeine has shown ergogenic

effects 6-h post-administration (4,5). Caffeine has first order biological half-life kinetics with a half-life of 5-h. As such, 5-mg/kg BW caffeine would likely reach an insignificant relative dosage of 2-mg/kg BW after 6.6-h:

$$k = \frac{\ln 2}{t_{1/2}} ; t = \frac{\ln \frac{[A]_t}{[A]_0}}{-k} ; t = \frac{\ln \frac{[A]_t}{[A]_0} \cdot t_{1/2}}{-\ln 2}$$

It would be unlikely for an ergogenic effect to take place after this time period. If an ergogenically equivalent transdermal dosage were applied, the patch may continue to release caffeine during exercise and prolong the ergogenic effect by increasing blood caffeine concentration at a given time. Furthermore, additional EnP applied after the initial dosage and rest period (whether transdermal or oral) may also increase blood caffeine concentration at a given time during exercise. The individual would not have to stop to redose for a continued ergogenic effect. Therefore, EnP may be beneficial for prolonged endurance performance or when the time of performance is uncertain.

Application Limitations

Additional factors such as the presence, quantity, and anatomy of hair follicles in the dermis, applied surface area, and adhesive properties of the patch may have affected the ability of caffeine to be delivered to the blood. The presence of hair follicles, especially those that penetrate the dermis into the hypodermis such as those in the chest area, may be the most important factor for transdermal caffeine delivery. Caffeine delivered via hair follicles, termed the follicular pathway, may account for up to 50.2-58.6% of

caffeine's delivery kinetics (24,28). Therefore, transdermal patch application on the chest instead of the upper arm is suggested for future research. Additionally, the relationship between patch surface area and caffeine concentration per surface area for differing adhesives should be investigated in large doses (i.e. mg caffeine vs. μ g caffeine) to determine the best options for transdermal delivery. Furthermore, future studies using caffeine patches should analyze blood caffeine concentrations in addition to exercise performance to allow comparison between transdermal and oral caffeine administration.

Conclusion

The present study's dosage of caffeine within an EnP was insufficient to elicit an ergogenic effect for both aerobic and anaerobic exercise tests. Due to small sample sizes in the present study, future research with larger samples is suggested to verify the absence of statistical significance. Also, a greater dose of topically applied caffeine may be needed for caffeine's effect to be present. Further research is needed to investigate the delivery kinetics of caffeine in large doses along with exercise tests measuring both performance and plasma caffeine concentration to allow for comparison to oral caffeine studies.

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