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The Effect of Caffeine Ingestion on Field Hockey Skill Performance Following Physical Fatigue

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This study examined the impact of caffeine ingestion on field hockey skill performance following high-intensity fatigue. Thirteen male hockey players (mean age = 21.1 ± 1.2 years) performed hockey sprint dribble and ball handling tests at rest and after a bout of total body fatigue (90% maximal capacity) following caffeine (5mg kg⁻¹) or placebo ingestion. Sprint dribble times were slower postfatigue compared with rest but were significantly faster postfatigue with caffeine compared with postfatigue with placebo ingestion (\( P < 0.01 \)). Ball handling scores were higher at rest compared with postfatigue, but scores postfatigue were higher following caffeine than placebo ingestion (\( P < 0.01 \)). Rating of perceived exhaustion (RPE) was lower (\( P < 0.01 \)) and readiness to invest physical (\( P < 0.01 \)) and mental effort (\( P = 0.01 \)) were significantly higher in the caffeine condition. Caffeine ingestion may therefore be effective in offsetting decrements in skilled performance associated with fatigue.

KEYWORDS physical exertion, effort, sports skill, ergogenic

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Caffeine is a widely used ergogenic aid that has “beneficial” effects on physical and mental performance and positively affects endurance exercise performance (Graham, 2001). Data with respect to the impact of caffeine on short-term, anaerobic performance tasks are less clear (Astorino & Roberson, 2010). Some authors have reported that caffeine ingestion is related to improved performance in high-intensity exercise (Doherty & Smith, 2005; Woolf Bidwell, & Carlson, 2008) whilst others have reported no effect of caffeine ingestion on anaerobically based exercise (Green Wickwire, McLester, & Gendle, 2007; Greer, Morales, & Coles, 2006). Recent work also has reported that caffeine ingestion improves soccer passing accuracy during 90-minute simulated soccer activity (Foskett Ali, & Grant, 2009). Research by Crowe et al. (2006) found no significant change in cognitive tasks (reaction time, number recall) or RPE and a potentially detrimental effect on performance of two 60-second cycle sprints following acute caffeine ingestion in 17 nonspecifically trained adults, compared with placebo ingestion. As high-intensity, anaerobic exercise is a feature of many sports, there is a need for further investigation of the impact of caffeine on this type of exercise (Astorino & Roberson, 2010; Davis & Green, 2009).

One suggestion for the efficacy of caffeine ingestion in improving performance is due to its role as a central stimulant that affects cognitive and psychomotor functioning particularly during activities that induce fatigue (Hogervorst et al., 2008; Kennedy & Scholey, 2004). This issue may be of interest to researchers as although the study of fatigue on performance has a long history, the data pertaining to the effect of exercise on skilled performance is equivocal (Lyons Al-Nakeeb, & Nevill, 2006a). Within the team sports context, fatigue may be the determining factor between winning and losing (Lyons Al-Nakeeb, & Nevill, 2006b). As such, the study of fatigue and its impact on performance generally but on execution of sport-specific motor skills specifically merits further scrutiny (Lyons et al., 2006a). Few studies, however, have examined the impact of anaerobically induced fatigue on skilled performance (Lyons et al., 2006a). This is surprising given that anaerobic fatiguing tasks are more reflective of the fatigue experienced during team games (Arnett DeLuccia, & Gilmartin, 2000).

Past work relating to the effects of fatigue on sports performance has been conducted by Lyons et al. (2006a) who reported soccer passing performance was reduced following 90% fatigue (determined via the number of split squats completed in 1 minute) compared with rest and moderate (70%) intensity fatigue. Lyons et al. (2006b) subsequently reported that basketball-passing performance was reduced following high-intensity fatigue (90% of the number of squat thrusts performed in 1 minute). They concluded that the impact of fatigue on skill performance appears to be most apparent after high-intensity exercise, but further research examining this topic was
imperative. This is important as authors have reported that the intensity of team games such as soccer and hockey is strenuous and results in a number of physiological changes that persist for up to 24 hours postperformance (Papapanagiotou et al., 2011). Understanding how ergogenic aids such as caffeine may offset these changes is therefore useful for scientists and nutritionists interested in athlete preparation.

Authors also have suggested that the performance-enhancing effect of caffeine is due to altered central nervous system function, possibly related to the attenuation of central fatigue effects (Kalmar & Caffarelli, 2004) and adenosine antagonism (Astorino & Roberson, 2010). As such, caffeine may have an important role in exercises where technical/tactical skills have a major influence (Hogervorst et al., 2008). Although studies have reported the effect of caffeine on exercise performance (Doherty & Smith, 2005; Graham, 2001; Green et al., 2007) and on performance of cognitive and psychomotor skills at rest (Kennedy & Scholey, 2004), few studies have examined the effect of caffeine ingestion on skilled performance following fatigue.

One study by Hogervorst et al. (2008) found that participants were significantly faster and cognitive performance, determined using the Stroop word-colour test, was improved following caffeine ingestion compared with ingestion of carbohydrate in trained cyclists. Likewise, Gillingham et al. (2004) reported that caffeine ingestion improved target detection and engagement speed during simulated military marksmanship exercises after a 2.5-hour loaded march and 1 hour of sandbag wall construction in 12 reserve soldiers.

It appears that, despite suggestions that caffeine enhances performance following fatigue, no studies have examined the effect of high-intensity fatigue following caffeine ingestion on the performance of a sport-specific motor skill. As many sports require skilled performance immediately following or during bouts of high-intensity fatigue, an examination of whether caffeine ingestion might be influential in offsetting fatigue-induced decrement in skilled performance would seem worthy of scrutiny. The aim of this study was to examine the impact of caffeine ingestion on field hockey skill performance following high-intensity total body fatigue. The study hypothesized that skill performance would be better, and RPE and readiness to invest effort enhanced, in the presence of caffeine ingestion compared with ingestion of a placebo following an acute bout of fatigue.

METHOD

Participants

Following institutional ethics approval and informed consent, 13 male field hockey players volunteered to participate. Mean (± S.D) age, height, and body mass were 21.2 ± 1.2 years, 1.78 ± 0.6m, and 75.8 ± 8.9kg,
respectively. A priori power calculations had indicated that 12 participants were needed for a large effect size (0.8), at an alpha level of 0.05 with 80% power. All participants competed in field hockey at a national level (mean ± S.D. years of formal, competitive hockey experience = 6.8 ± 3.6 years). They were currently participating in >12 hours a week of programmed hockey training.

Participants completed 24th diet and exercise recalls before each trial, followed the same diet on the day preceding each trial, and refrained from caffeine intake in the 48h and from vigorous exercise in the 24h prior to testing. Habitual caffeine consumption, derived from Maughan (1999), and general health status were assessed using a prestudy questionnaire. To ensure familiarity with the effects of caffeine whilst also controlling for individual differences in reactivity to caffeine from caffeine habituation, only moderate caffeine users (ingesting approximately 250 mg day\(^{-1}\)) were included in the study.

Procedure

This study used a repeated measures design whereby participants attended four testing sessions. In the first session, participants completed baseline measures in the hockey slalom sprint dribble test (Lemmink Elferink-Gemser, & Visscher, 2004) and the Chapman stick handling test (Chapman, 1982). Although participants had prior experience of performing the tests and the type of movements involved, they were allowed five attempts on each test to familiarize themselves with the test protocol.

To establish individual fatigue intensities, participants were required to perform as many squat thrusts as possible in one minute. This maximal workload was used to define high-intensity fatigue in later testing sessions by calculating 90% of the maximum number of squat thrusts performed. This protocol has been used by previous authors to examine the impact of total body fatigue on performance (Lyons et al., 2006b) and allows researchers to establish fatigue intensities based on the fitness level of each participant. It also ensures that each participant is working at the same intensity (Lyons et al., 2006b). The fatiguing task was chosen because squat thrusts impact heavily on the muscle groups used in hockey performance generally and the skill tests employed in this study.

The participants then performed the hockey skill tests under three conditions: rest, 90% of maximal repetitions within one minute following caffeine ingestion, and 90% of maximal repetitions following placebo ingestion. To ensure that each participant was being fatigued to the correct intensity a metronome (Wittner, Germany) was set to the appropriate cadence required. Testing was counterbalanced and treatment groups were assigned in a double blind manner. To minimize the effects of the previous testing, at least 72h were given between successive testing sessions. All tests were performed within a time difference of ± 1h of the first test.
In regard to substance administration, participants ingested 5mg kg$^{-1}$ caffeine diluted into 250ml of artificially sweetened water or a placebo where 5mg kg$^{-1}$ of dextrose diluted into 250ml of artificially sweetened water drink was consumed. The 5mg kg$^{-1}$ dose of caffeine was employed as this is within the midrange of caffeine doses (3–9mg kg$^{-1}$) shown to be ergogenic, has been previously used in studies examining the effect of caffeine ingestion on high-intensity exercise performance (Woolf et al., 2008), and is regarded as in the “optimal” range for an ergogenic effect (Graham, 2001). All solutions were administered in opaque 750ml water bottles to prevent participants or researchers actually seeing the solutions themselves. Solutions were consumed 1h before each exercise trial as plasma caffeine concentration is maximal 1h after ingestion of caffeine (Graham, 2001).

Hockey Skill Performance Tests

Two field hockey skill tests: the hockey slalom sprint dribble test (Lemmink et al., 2004) and the Chapman stick handling test (Chapman, 1982) were employed and performed at rest and in the two fatigue conditions. In all cases, the sprint dribble test was performed first, followed by the stick handling test. To ensure that performance on the skill tests was conducted in a truly fatigued state, a very short time lag (2–3 seconds) was allowed from achieving the desired fatigue level and the start of the sprint dribble test. This was immediately followed by the ball handling test to ensure that performance of both skill tests was completed within 40–50 seconds of the fatigue task.

The Hockey Slalom Sprint Dribble Test

The slalom sprint dribble test (Lemmink et al., 2004) assesses field hockey specific slalom sprint dribble performance. This test originally was trialed in a sample of 34 field hockey players over a 4-week, test–retest period and also was compared with sprint slalom time without dribbling ($r = 0.91$) and hockey ball slalom dribble ability ($r = 0.78$; Lemmink et al., 2004). The protocol consisted of a maximal slalom run through 12 cones placed in a zigzag pattern while dribbling a hockey ball. The course length was 15 meters with cones paced 2 meters apart (players thus cover 30m per trial). Slalom sprint dribble times were recorded using infrared timing gates (Brower Speedtrap II, Brower Systems Inc., USA) and the protocol followed that previously described (Lemmink et al., 2004). Reliability of this test also was supported through pilot data with 10 male university level hockey players (mean age = 20.2 ± 0.9 years) where intraclass correlation coefficient for 2-week test–retest reliability was $R = 0.8$ (95% confidence intervals = 0.69–0.97).
The Chapman Ball Handling Test

The Chapman hockey test protocol (Chapman, 1982) is a validated measure of hockey stick handling ability. This utilizes two concentric circles, with the outer circle divided into 3 equally sized segments of 120 degrees. The inner circle measures 4.5 feet in diameter and the outer circle 9.5 feet in diameter. During the test protocol participants dribbled a hockey ball from outside of both the concentric circles and into the center of the circular target area through one of the segments and dribbled the ball out of an alternative segment as many times as possible in 15 seconds with higher scores reflecting greater ball/stick handling ability. Prior data has reported good validity (r = .64, when compared to expert rating of players’ hockey ability) and test–retest reliability as a test of hockey stick handling (R = .89; Chapman, 1982). It also has been described as a good measure of hockey ball control ability (Sunderland, Cooke, Milne, & Nevill, 2006) but not total hockey skill. Pilot data examining 2-week test–retest reliability of the Chapman ball handling test in the present study was found to be R = 0.88 (95% confidence intervals = 0.66–0.96).

Perceptual Measures

On completion of each testing session, RPE was determined using the Borg 6–20 RPE scale (Borg, 1970). In light of criticisms leveled at prior studies employing RPE as the only psychophysiological measure of perceived effort (Tenenbaum et al., 2001), participants were asked to rate their readiness to invest both physical and mental effort prior to performance in the 2 fatigue testing sessions. This measure was based on recommendations for assessing perceived effort in exercise testing (Midgley, McNaughton, Polman, & Marchant, 2007) and asked participants to rate how physically and mentally ready they were to invest effort using visual analogue scales incorporating a range of 0–10, with higher scores reflecting greater readiness to invest effort.

Statistical Analysis

Repeated measures analysis of variance (ANOVA) was used to assess differences in sprint dribble times and Chapman test scores at baseline, postfatigue with caffeine ingestion (post-FCAF) and postfatigue with placebo ingestion (post-FPLA). Bonferroni post-hoc multiple comparisons were used and partial eta squared ($\eta^2$) was used as a measure of effect size. Differences in RPE scores, readiness to invest physical effort and mental effort post-FCAF and post-FPLA were assessed using a series of paired t tests. Alpha level was set at $P = 0.05$ a priori and SPSS version 16 (SPSS Inc., Chicago, USA) was used for all analyses.
RESULTS

Repeated measures ANOVA indicated a significant difference in slalom sprint dribble time across conditions (F 2, 24 = 26.9, P < 0.01, partial η² = .692). Bonferroni post-hoc indicated that sprint dribble times were significantly slower post-FCAF (mean diff = −1.279, P < 0.01) and post-FPLA (mean diff = −2.799, P < 0.01) compared with baseline values. Sprint dribble times were significantly slower post-FPLA compared with post-FCAF (mean diff = 1.550, P < 0.01). Mean ± S.D. of sprint dribble times at baseline and post-FCAF and post-FPLA, respectively, are presented in Figure 1.

Scores on the hockey ball handling test also revealed significant differences across conditions (F 2, 24 = 50.6, P < 0.01, partial η² = .809). Bonferroni post-hoc comparisons revealed that scores on the Chapman test were significantly higher at baseline compared with post-FCAF mean diff = 1.692, P < 0.01) and post-FPLA (mean diff = 2.799, P < 0.01). Post-fatigue scores were higher after caffeine ingestion in comparison with scores after placebo ingestion (mean diff = 1.07, P < 0.05). Mean ± S.D. of Chapman test scores at baseline, post-FCAF, and post-FPLA, respectively, are presented in Figure 2.

Paired t tests for RPE and readiness to invest effort revealed that RPE values were significantly lower post-FCAF compared with post-FPLA (t = −4.782, df = 12, P < 0.01). Scores for readiness to invest physical (t = 2.952, df = 12, P < 0.01) and mental effort (t = 3.351, df = 12, P < 0.01) were significantly higher pre-FCAF compared with pre-FPLA. Mean ± S.D. of RPE, readiness to invest physical and mental effort, was 16.9 ± 1.2, 6.25 ± 1.7 and 7.2 ± 1.3 for the caffeine trial and 18.3 ± 1.0, 5.4 ± 1.9 and 6.0 ± 1.1 for the placebo trial.

**FIGURE 1** Mean ± S.D. of sprint dribble times at baseline and postfatigue following caffeine and placebo ingestion.
DISCUSSION

The results of this study evidence that total body fatigue negatively influences skilled performance. The novel aspect of this study is that caffeine ingestion may offset the decrement in skilled performance associated with high-intensity fatigue compared with placebo ingestion. These results add support to prior claims that caffeine enhances sport performance (Astorino & Roberson, 2010), particularly where technical skills are important (Hogervorst et al., 2008).

The findings of the present study are congruent with those of Gillingham et al. (2004). The fatigue protocol employed by Gillingham et al., although occupationally relevant, however, may have resulted in participants working at different exercise intensities, making it difficult to draw conclusions regarding the effect of caffeine on performance when fatigued. Conversely, the fatigue task employed in the present study did ensure that each participant was working at 90% of his own individual maximal capacity.

Several possible explanations for the effect of caffeine in offsetting fatigue following high-intensity exercise have been proposed. Early data suggested increased lipolysis and sparing of muscle glycogen (Costill, Dlasky, & Fink, 1978) and increased motor unit recruitment (VanHandel, 1983). Subsequent research revealed that caffeine does not spare glycogen (Jackman, Wendling, Friars, & Graham, 1996) and as short-term, high-intensity exercise is not limited by carbohydrate availability, increased lipolysis does not explain the ergogenic effect of caffeine (Astorino & Roberson, 2010). Research also shows no effect of caffeine ingestion on muscle activation during short-term, high-intensity exercise (Greer et al., 2006).
Increased intracellular calcium concentrations (Doherty, Smith, Hughes, & Davison, 2004) and/or altered excitation–contraction coupling (Carr, Dawson, Schneiker, Goodman, & Lay, 2008) also have been proposed as potential mechanisms for caffeine’s action. These effects however, occur only at supraphysiological caffeine doses, impractical for humans; have been demonstrated only in animal-based research (Rosser, Walsh, & Hogan, 2009), and subsequently have been discounted in relation to anaerobically based exercise (Astorino & Roberson, 2010).

Other authors have suggested that the effect of caffeine lies within the central nervous system (CNS). Davis et al. (2003) reported that caffeine delays fatigue via stimulation of the CNS by acting as an adenosine antagonist. Adenosine, an endogenous neuromodulator, has an inhibitory effect on central excitability. It preferentially inhibits the release of excitatory neurotransmitters and decreases the firing rate of central neurons (Kalmar & Cafarelli, 2004), and a reversal in the inhibitory effects of adenosine after caffeine administration has been reported (Kalmar & Cafarelli, 2004). The data purporting to the effect of caffeine ingestion on adenosine antagonism, however, is predominantly based on animal studies, which, for example, document increased run time to fatigue (60% longer) in rats with caffeine compared with an adenosine antagonist (Davis et al., 2003).

One other, less explored, potential mechanism for the ergogenic effect of caffeine on high-intensity exercise performance is through the electrolyte potassium (Crowe et al., 2006). There is net movement of potassium out of muscle cells during exercise, resulting in an increase in extracellular potassium concentration, and disturbance of the muscle resting membrane potential, which may cause muscle fatigue (Lindinger, Graham, & Spreit, 1993). As caffeine decreases plasma potassium concentrations at rest and postexercise (Doherty, Smith, Davison, & Hughes, 2002; Lindinger et al., 1993), caffeine may enhance performance due to an increase in potassium uptake and maintenance of resting membrane potential of muscle cells. Although decreased plasma potassium concentration may contribute to ergogenic effects of caffeine, however, they are unlikely to be the sole mediator of its effects (Crowe et al., 2006).

Given the focus of the present study on the effects of fatigue on sport skill performance with the presence of caffeine or a placebo, the results need to be considered in the context of wider motor control. One recent study reported an increase in movement times, irrespective of task difficulty, when participants were asked to perform fast and accurate movements aiming at different size targets (i.e., examining Fitts’ law) before and after a fatiguing exercise (reduction in maximum voluntary force of 30%; Missenard, Mottet, & Perrey, 2009). Missenard et al. (2009) concluded that accurate movements after fatigue are possible but at the expense of movement duration. The results elicited in the present study would add some support to these claims. The measure of performance for the hockey dribble
test is the time taken to perform the sprint dribble, whereas the Chapman test is time limited (15 seconds). In line with Missenard et al. (2009), it could be expected, and as was the case, that sprint dribble time is increased and Chapman test score decreased in the presence of fatigue. As performance was enhanced post-FCAF compared with post-FPLA, it might be that the optimal strategy employed by the CNS in order to exhibit increased signal-dependent noise in motor commands to preserve task success in the presence of fatigue is maximized in the presence of caffeine compared with placebo. This is speculative, however, and future research is required to verify this suggested.

The results of the current study also support prior research that has reported caffeine ingestion to dampen RPE during exercise (Doherty & Smith, 2005). The current study also employed measures of readiness to invest effort, as has been recommended (Midgley, et al., 2007), and indicated that participants reported greater readiness to invest both mental and physical effort following caffeine ingestion. It may be that caffeine ingestion results in psychological changes whereby participants feel more able to provide maximal effort compared with ingestion of placebo. As this is the first study to report readiness to invest effort after caffeine ingestion, further research examining this concept is needed.

The current study is not without limitations. The hockey skill tests employed both require rapid muscle activity in order to score well. It may therefore be that improved performance post-FCAF in the current study is more a result of enhanced ability to perform high-intensity exercise rather than true improvements in motor skill. Prior evidence has suggested that the effect of fatigue on sport skill differs depending on the participants’ skill level (Lyons et al., 2006b). It may therefore be beneficial to examine the effect of caffeine ingestion on skilled performance postfatigue in expert and novice performers. There is also a need to consider the efficacy of caffeine ingestion on hockey skill performance using a more ecologically valid task. If caffeine ingestion truly enhances skilled performance following acute fatigue as demonstrated here, this needs exploration following a protocol that mimics the demands and duration of competitive field hockey.

REFERENCES


Caffeine and Fatigue in Hockey


