PROOF COVER SHEET

Journal acronym:	RJSP
Author(s):	Svein Arne Pettersen, Peter Krustrup, Mads Bendiksen, Morten Bredsgaard Randers, Joao Brito, Jens Bangsbo, Yun Jin and Magni Mohr
Article title:	Caffeine supplementation does not affect match activities and fatigue resistance during match play in young football players
Article no:	965189
Enclosures:	1) Query sheet 2) Article proofs

Dear Author,

1. Please check these proofs carefully. It is the responsibility of the corresponding author to check these and approve or amend them. A second proof is not normally provided. Taylor & Francis cannot be held responsible for uncorrected errors, even if introduced during the production process. Once your corrections have been added to the article, it will be considered ready for publication.

Please limit changes at this stage to the correction of errors. You should not make trivial changes, improve prose style, add new material, or delete existing material at this stage. You may be charged if your corrections are excessive (we would not expect corrections to exceed 30 changes).

For detailed guidance on how to check your proofs, please paste this address into a new browser window: http://journalauthors.tandf.co.uk/production/checkingproofs.asp

Your PDF proof file has been enabled so that you can comment on the proof directly using Adobe Acrobat. If you wish to do this, please save the file to your hard disk first. For further information on marking corrections using Acrobat, please paste this address into a new browser window: http://journalauthors.tandf.co.uk/production/acrobat.asp

2. Please review the table of contributors below and confirm that the first and last names are structured correctly and that the authors are listed in the correct order of contribution. This check is to ensure that your name will appear correctly online and when the article is indexed.

Sequence	Prefix	Given name(s)	Surname	Suffix
1		Svein Arne	Pettersen	
2		Peter	Krustrup	
3		Mads	Bendiksen	
4		Morten Bredsgaard	Randers	
5		Joao	Brito	
6		Jens	Bangsbo	
7		Yun	Jin	
8		Magni	Mohr	

Queries are marked in the margins of the proofs, and you can also click the hyperlinks below.

AUTHOR QUERIES

General points:

1. **Permissions:** You have warranted that you have secured the necessary written permission from the appropriate copyright owner for the reproduction of any text, illustration, or other material in your article. Please see http://journalauthors.tandf.co.uk/permissions/usingThirdPartyMaterial.asp.
2. **Third-party content:** If there is third-party content in your article, please check that the rightsholder details for re-use are shown correctly.
3. **Affiliation:** The corresponding author is responsible for ensuring that address and email details are correct for all the co-authors. Affiliations given in the article should be the affiliation at the time the research was conducted. Please see http://journalauthors.tandf.co.uk/preparation/writing.asp.
4. **Funding:** Was your research for this article funded by a funding agency? If so, please insert 'This work was supported by <insert the name of the funding agency in full>', followed by the grant number in square brackets '[grant number xxxx]'.
5. **Supplemental data and underlying research materials:** Do you wish to include the location of the underlying research materials (e.g. data, samples or models) for your article? If so, please insert this sentence before the reference section: 'The underlying research materials for this article can be accessed at <full link> / description of location [author to complete]'. If your article includes supplemental data, the link will also be provided in this paragraph. See <http://journalauthors.tandf.co.uk/preparation/multimedia.asp> for further explanation of supplemental data and underlying research materials.
6. The **CrossRef database** (www.**crossref**.org/) has been used to validate the references. Changes resulting from mismatches are tracked in red font.

AQ1 Please check and confirm whether the edits made in the author affiliations are correct.

AQ2 Please check and clarify whether the citation "Krustrup et al., 2006" refers "Krustrup et al., 2006a" or "Krustrup et al., 2006b" in the text globally.

AQ3 Notes given under Figure 1A and 1B and Figure 1A–1C have been included in Figure 1 and 2 legends, respectively. Please check and confirm.

AQ4 The reference "McKenna et al., 2008" is cited in the text but is not listed in the references list. Please either delete in-text citation or provide full reference details following journal style [http://www.tandf.co.uk/journals/authors/style/reference/tf_APA.pdf].

AQ5 The reference "Gregson et al., 2010" is cited in the text but is not listed in the references list. Please either delete in-text citation or provide full reference details following journal style [http://www.tandf.co.uk/journals/authors/style/reference/tf_APA.pdf].

AQ6 The reference "Wiley et al., 2012" is cited in the text but is not listed in the references list. Please either delete in-text citation or provide full reference details following journal style [http://www.tandf.co.uk/journals/authors/style/reference/tf_APA.pdf]. Also please check the subsequent occurrences.

AQ7 The reference "Mohr et al., 2007" is cited in the text but is not listed in the references list. Please either delete in-text citation or provide full reference details following journal style [http://www.tandf.co.uk/journals/authors/style/reference/tf_APA.pdf].

AQ8 The reference "Iaia et al., 2008" is cited in the text but is not listed in the references list. Please either delete in-text citation or provide full reference details following journal style [http://www.tandf.co.uk/journals/authors/style/reference/tf_APA.pdf].

AQ9 The reference "Bangsbo et al., 2006" is listed in the references list but is not cited in the text. Please either cite the reference or remove it from the references list.

AQ10 The reference "Iaia et al., 2009" is listed in the references list but is not cited in the text. Please either cite the reference or remove it from the references list.

AQ11 The reference "Krustrup et al., 2006a" is listed in the references list but is not cited in the text. Please either cite the reference or remove it from the references list.

AQ12 The reference "Krustrup et al., 2006b" is listed in the references list but is not cited in the text. Please either cite the reference or remove it from the references list.

AQ13 The reference "Wylie et al., 2013" is listed in the references list but is not cited in the text. Please either cite the reference or remove it from the references list.

How to make corrections to your proofs using Adobe Acrobat/Reader

Taylor & Francis offers you a choice of options to help you make corrections to your proofs. Your PDF proof file has been enabled so that you can edit the proof directly using Adobe Acrobat/Reader. This is the simplest and best way for you to ensure that your corrections will be incorporated. If you wish to do this, please follow these instructions:

1. Save the file to your hard disk.

2. Check which version of Adobe Acrobat/Reader you have on your computer. You can do this by clicking on the "Help" tab, and then "About".

If Adobe Reader is not installed, you can get the latest version free from http://get.adobe.com/reader/.

3. If you have Adobe Acrobat/Reader 10 or a later version, click on the "Comment" link at the right-hand side to view the Comments pane.

4. You can then select any text and mark it up for deletion or replacement, or insert new text as needed. Please note that these will clearly be displayed in the Comments pane and secondary annotation is not needed to draw attention to your corrections. If you need to include new sections of text, it is also possible to add a comment to the proofs. To do this, use the Sticky Note tool in the task bar. Please also see our FAQs here: http://journalauthors.tandf.co.uk/production/index.asp.

5. Make sure that you save the file when you close the document before uploading it to CATS using the "Upload File" button on the online correction form. If you have more than one file, please zip them together and then upload the zip file.

If you prefer, you can make your corrections using the CATS online correction form.

Troubleshooting

Acrobat help: http://helpx.adobe.com/acrobat.html
Reader help: http://helpx.adobe.com/reader.html

Please note that full user guides for earlier versions of these programs are available from the Adobe Help pages by clicking on the link "Previous versions" under the "Help and tutorials" heading from the relevant link above. Commenting functionality is available from Adobe Reader 8.0 onwards and from Adobe Acrobat 7.0 onwards.

Firefox users: Firefox's inbuilt PDF Viewer is set to the default; please see the following for instructions on how to use this and download the PDF to your hard drive:
http://support.mozilla.org/en-US/kb/view-pdf-files-firefox-without-downloading-them#w_using-a-pdf-reader-plugin

Journal of Sports Sciences, 2014
Vol. 00, No. 00, 1–8, http://dx.doi.org/10.1080/02640414.2014.965189

Routledge
Taylor & Francis Group

Caffeine supplementation does not affect match activities and fatigue resistance during match play in young football players

SVEIN ARNE PETTERSEN[1], PETER KRUSTRUP[2], MADS BENDIKSEN[3], MORTEN BREDSGAARD RANDERS[3], JOAO BRITO[4], JENS BANGSBO[3], YUN JIN[5] & MAGNI MOHR[2]

[1]*Faculty of Health Sciences, The Regional Centre for Sport, Exercise and Health–North, University of Tromsoe, Tromso, Norway,* [2]*Sport and Health Sciences, College of Life and Environmental Sciences, University of Exeter, Exeter, UK,* [3]*Department of Nutrition, Exercise and Sports, Copenhagen Centre for Team Sport and Health, University of Copenhagen, Copenhagen, Denmark,* [4]*National Sports Medicine Program, Aspetar, Qatar Orthopaedic and Sports Medicine Hospital, Doha, Qatar and* [5]*Clarity, School of Computing, Dublin City University, Dublin, Ireland*

(*Accepted 9 September 2014*)

Abstract

The study examined the effect of caffeine supplementation on match activities and development of fatigue during a football match. In a randomised, double-blind cross-over design, two experimental football games separated by 7 days were organised between the junior teams of two professional football clubs (17.6 ± 1.1 years (±*s*), 71.7 ± 6.9 kg, 13.9% ± 5.0% body fat). The players ingested either a capsule of 6 mg · kg^{-1} b.w. caffeine or placebo (dextrose) 50 min prior to the matches. Match activities were assessed using the ZXY match analysis system, and a Yo-Yo intermittent recovery test–level 2 (Yo-Yo IR2) was conducted immediately post-game. Heart rate was monitored throughout the game, and blood samples were obtained at baseline, half-time and after the game. There were no differences between caffeine and placebo regarding total distance covered (10,062 ± 916 vs 9854 ± 901 m), high-intensity running (557 ± 178 vs 642 ± 240 m), sprinting distance (109 ± 58 vs 112 ± 69 m) or acceleration counts (123 ± 30 vs 126 ± 24). In both trials, players displayed lower ($P < 0.05$) values in total distance and acceleration counts in the last 15 min compared to all other 15-min periods of the matches. Post-game Yo-Yo IR2 performance was not different between game trials (caffeine: 829 ± 322 m; placebo 819 ± 289 m). In conclusion, oral caffeine administration does not appear to have an ergogenic effect in young football players during match play.

Keywords: *intermittent exercise performance, ergogenic effect, Yo-Yo IR2 test, blood lactate, match analysis, soccer*

Introduction

Caffeine supplementation in relation to athletic performance has been studied extensively during the last two decades (see review Tarnopolsky, 2010). Several studies tested the hypothesis that caffeine may have an ergogenic effect during endurance trials and average improvements ranging between 3% and 5% have been reported (Ganio, Klau, Casa, Armstrong, & Maresh, 2009; Hodgson, Randell, Jeukendrup, & Earnest, 2013). Caffeine has in some studies shown to increase fat oxidation during prolonged exercise events (Jeukendrup & Randell, 2011), which may induce glycogen sparing during endurance exercise scenarios. Moreover, caffeine or breakdown products such as paraxanthine and theophylline may also reduce the degree of central fatigue during prolonged exercise (Nybo, 2010). In addition, caffeine may also increase high-intensity exercise performance due to potential improved muscle interstitial K^+ regulation (Mohr, Nielsen, & Bangsbo, 2011) and sarcoplasmatic Ca^{2+} handling (Fitts, 1994), or central activation (Gandevia, 2001). The above-mentioned mechanisms are all likely to play a role in performance enhancement during football match play (Krustrup et al., 2011; Mohr & Krustrup, 2013; Mohr, Krustrup, & Bangsbo, 2005).

Football match play has been demonstrated to be a physically demanding sport event where prolonged intermittent exercise is conjoined with short periods with high-intensity exercise (Bangsbo, 1994; Mohr, Krustrup, Andersson, Kirkendal, & Bangsbo, 2008). Thus, the physical demands encompass both an endurance component and high-intensity exercise abilities, which involved

Correspondence: Magni Mohr, Sport and Health Sciences, College of Life and Environmental Sciences, University of Exeter, Exeter, UK.
E-mail: M.Mohr@exeter.ac.uk

different types of fatiguing mechanisms (Bangsbo, Iaia, & Krustrup, 2007; Mohr et al., 2005). Indeed, fatigue has been demonstrated to occur towards the end of a football game in adult players, as well as during the most intense game periods (Krustrup, Zebis, Jensen, & Mohr, 2010; Krustrup et al., 2006; Mohr & Krustrup, 2013; Mohr, Krustrup, & Bangsbo, 2003; Mohr et al., 2010). Similar fatigue patterns have been shown in youth players (Mendez-Villanueva, Buchheit, Simpson, & Bourdon, 2013). The fatigue development in the final stages of a game has been linked to muscle glycogen depletion in individual or subcellular compartments (Krustrup et al., 2006, 2011). Therefore, caffeine supplementation may delay muscle glycogen degradation and the degree of fatigue at the end of a game through elevated fat oxidation (Jeukendrup & Randell, 2011). Moreover, fatigue during the most intense game periods in a football game has suggested to be associated with a high anaerobic energy turnover and/or extracellular K^+ accumulation (Bangsbo et al., 2007; Iaia, Perez-Gomez, Nordsborg, & Bangsbo, 2010; Mohr et al., 2005). Since caffeine may increase the glycolytic flux (Graham, 2001) and improve interstitial K^+ regulation (Mohr et al., 2011), fatigue resistance in the most intense periods of the game might be stimulated by caffeine intake.

Thus, the aim of the present study was to evaluate the effects of caffeine supplementation on high-intensity runs, sprinting performance, accelerations and the development of fatigue during and after a football match in high-level young players.

Methods

Participants

Twenty-two players from the reserve teams of two professional Norwegian football clubs (age, 17.6 ± 1.1 years; body mass, 71.7 ± 6.9 kg; body fat percentage, 13.9% ± 5.0%) participated in the study. The players are competing on regional and national level. Nineteen outfield players took part in two full 90-min experimental matches organised by the researchers. The players represented all playing positions. Goalkeepers were also excluded when analysing performance variables, since their activity pattern is different compared to outfield players. All participants were informed of all potential risks and discomforts associated with the experiment before giving their written consent to participate. The study conformed to the code of Ethics of World Medical Association (Declaration of Helsinki) and was institutionally approved.

Experimental design

In a randomised, double-blind cross-over design, two experimental football matches separated by 7 days were completed towards the end of the competitive season. The players arrived at the stadium 2 h prior to the games. The players were instructed to avoid any demanding exercise the day before the games, as well as intake caffeine containing items on the experimental games. The players were asked to follow the normal pre-game nutritional protocol on the day prior to the games. Also the players were asked to note the food intake prior to game 1 and encouraged to replicate this before game 2. Both games were played outdoors at the same stadium with artificial grass, starting at the same hour in the afternoon. The ambient temperatures at the start of the games were 10.4°C and 11.1°C, and the humidity was 64% and 83% in game 1 and 2, respectively. The pre-game and half-time procedures, as well as the coaching during the game, were similar to competitive game scenarios. The same match officials were refereeing the two games. Within 5 min after the two games, the Yo-Yo intermittent recovery test–level 2 (Yo-Yo IR2) was completed. Fifty minutes prior to the warm-up sessions, either caffeine (Merck, Darmstadt, Germany) or placebo (dextrose) was taken orally in a gelatine capsule (6 mg · kg^{-1} b.w. corresponding to 436 ± 22 mg in total). None of the participants were regular coffee-drinkers.

Players were weighed wearing shorts, t-shirt and socks (Seca 750, Hamburg, Germany) both before and after the matches. Each player had a personal 1-L bottle with decilitre markers containing water. Replacement of water was noted to control for the total intake after pre-match weighing. In the 15 min half-time break, players were only allowed to drink water. The individual fluid intake was not controlled during the games, but only assessed.

Post-match body mass was calculated after correction for ingested fluids and urine passed. Body fat percentage was calculated using the four skinfold method (Durnin & Womersley, 1974).

Physiological measurements and testing

Blood glucose (Accu-Check Aviva, Roche, Germany) and lactate concentration (Lactate Pro, Arkray, KDK, Japan) hand-held portable analysers were used to determine blood glucose and lactate concentration levels, respectively, from 5 μL samples taken from the index fingertip in a rested state prior to the warm-up, before the start of the game, at the half-time and after the game. Additionally, lactate concentration was drawn

after the Yo-Yo IR2 performed in extension of the games. The Yo-Yo IR2 consists of repeated 2 × 20 m runs back and forth between the start and finish line at a progressively increased speed controlled by audio bleeps from a CD recorder (see Krustrup et al., 2006). Between the running bouts, the participants had a 10-s active recovery period where they jogged around a cone placed 5 m behind the finish line. When the participants twice failed to reach the finish line in time, the distance covered was recorded, which was used as the test result (Krustrup et al., 2006). Heart rate was noted in 5-s intervals (Team System 2, Polar Electro, Kempele, Finland) during the whole experimental setting. Heart rate peak (HR_{peak}) was defined from the highest heart rate value obtained in the Yo-Yo IR2 test.

Match analysis procedures

The activity profiles of the players were monitored by ZXY Sport Tracking System (Trondheim, Norway; Bendiksen et al., 2013). Each player wore a belt with an electronic sensor system at the player's lumbar. The system uses a fixed default resolution of 20 Hz for each belt. High-intensity running is defined as speed >19.8 km · h^{-1} and sprinting >25.2 km · h^{-1}. Acceleration counts are defined as a positive or negative change in speed more than 2 m · s^{-2}.

Statistical analyses

Data were analysed using SPSS 21.0 for Windows (SPSS Inc., Chicago, IL, USA). Values are presented as means ± *s*. Two-way ANOVA for repeated measurements was adopted to analyse the time effect (different measurement points), treatment effect (caffeine and placebo) and their interactions if there was any, regarding performance parameters, heart rate, blood lactate and blood glucose. Mauchly's test of sphericity was deployed; if any effect was found to have violated the assumption, a correction was made according to the Epsilon to adjust the degree of freedom, so as to result in a different *P* value. Additionally, any effect with *P* value less than 0.05 was examined through pairwise comparisons. Bonferroni adjustments were utilised for multiple comparisons. Differences in post-match Yo-Yo IR2 performance and post-match body weight were evaluated by a Student's paired t-test. Correlations between selected variables were evaluated using Pearson's product moment test. A significance level of 0.05 was chosen. Cohen's *d* was calculated and interpretation of the magnitude of the effect sizes were done according to Hopkins, Marshall, Batterham, and Hanin (2009).

Results

Match activities

No differences were observed between caffeine and placebo in total running, high-intensity and sprinting distance covered, or the number of accelerations during matches (Table I). Total distance and acceleration counts were lower ($P < 0.05$) in the last 15 min within both trials (Figure 1).

No differences were observed between trials when comparing the most intense 5-min periods of high-intensity running, sprinting distance and acceleration counts with the following 5 min, average 5 min and the final 5 min of the match. On the other hand, in all performance parameters within each match, the most intense 5-min periods were different from all the other measuring points ($P < 0.05$; Figure 2). Sprinting distance, high-intensity running and acceleration counts were lower ($P < 0.05$) than average values in the 5-min periods following the peak 5-min period (Figure 2). Acceleration counts in the final 5 min of the game were different ($P < 0.05$) from the average 5-min periods throughout the game (Figure 2).

Table I. Overall match performance, heart rate data and Yo-Yo IR2 performance after the match for the caffeine and placebo groups ($n = 19$).

Group	Total distance (m)	HIR (m)	Sprinting (m)	Acc counts	% of HR_{peak}	Yo-Yo (m)
Caffeine	10,062 (916)	557 (178)	109 (58)	123 (31)	85.6 (4)	829 (328)
Placebo	9854 (901)	642 (240)	112 (69)	126 (24)	86.1 (3)	819 (289)
P-value	0.134	0.140	0.836	0.669	0.670	0.906
d	0.23 (small)	0.40 (small)	0.05 (trivial)	0.11 (trivial)	0.15 (trivial)	0.03 (trivial)

Note: Values are presented as means ± *s*. Match performance variables include total distance, high-intensity running (HIR), sprinting and the number of accelerations (Acc counts).

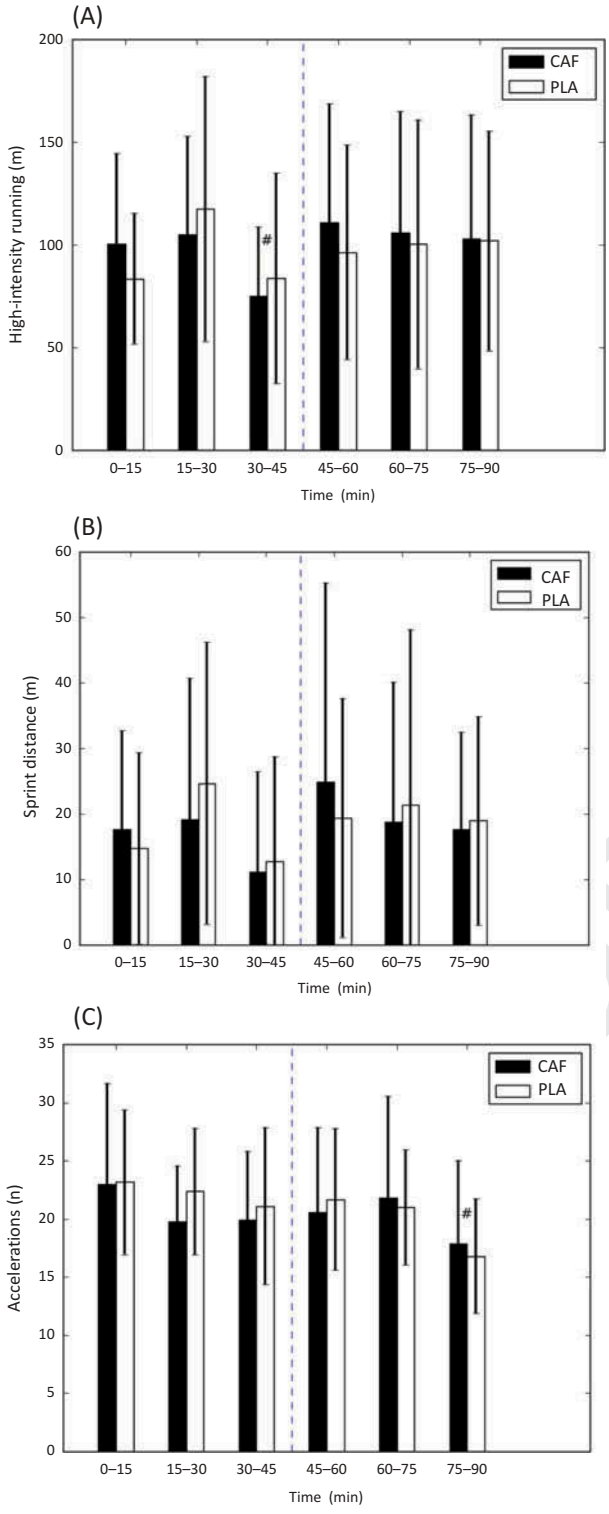

Figure 1. Performance data in two football matches for caffeine and placebo trials (n = 19) in 15-min intervals. Variables include (A) high-intensity running (HIR) (no treatments difference; # HIR in the last 15 min in first half is lower than that in 15–30 min (P = 0.011) and last 15-min period (P = 0.021)); (B) sprinting (no differences between treatments across time or between time periods); and (C) acceleration counts (Acc counts) (# Acc in the last quarter is less than those in other periods except for the 30–45 min period; period 75–90 vs period 0–15 (P = 0.001); period 75–90 vs period 15–30 (P = 0.002); period 75–90 vs period 45–60 (P = 0.006); period 75–90 vs period 60–75 (P = 0.035)). Data are presented as means ± s.

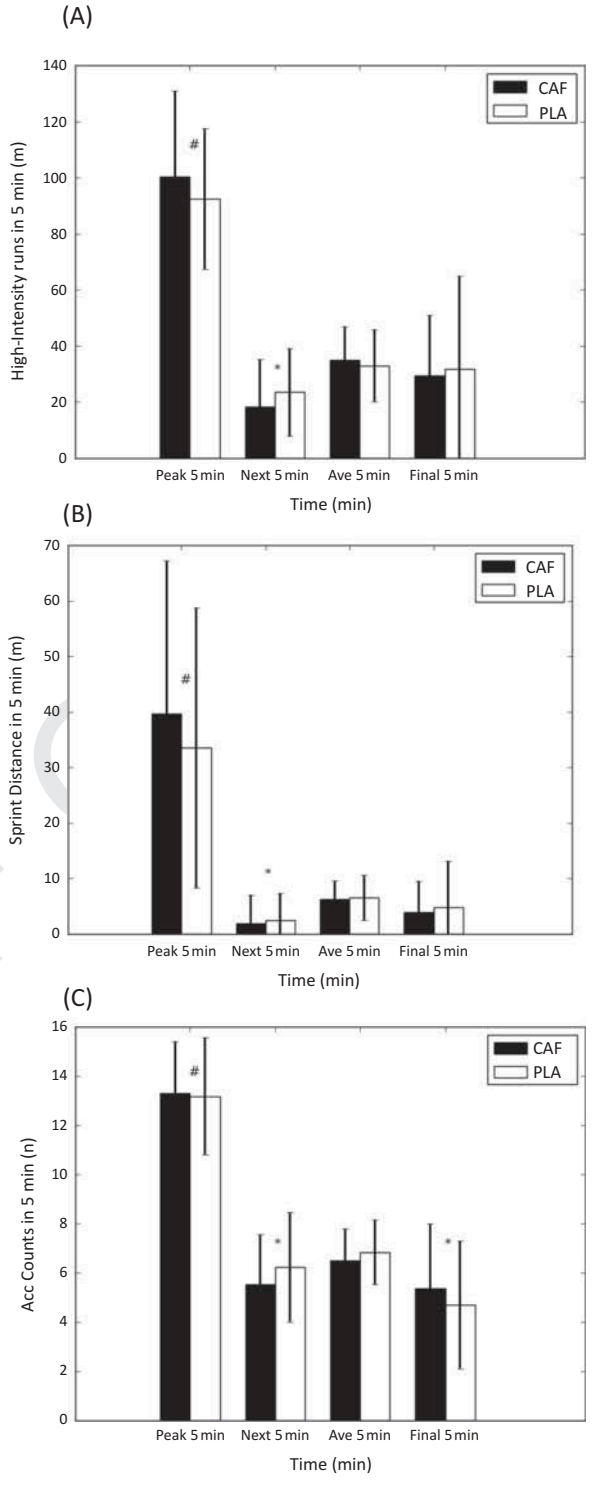

Figure 2. # Different from the other 3 periods * Different from average 5 min (A) high-intensity running (HIR) (peak 5 min > next 5 min (P = 0.000); peak 5 min > ave 5 min (P = 0.000); peak 5 min > final 5 min (P = 0.000); next 5 min < ave 5 min (P = 0.001)); (B) sprinting (peak 5 min > next 5 min (P = 0.000); peak 5 min > ave 5 min (P = 0.000); peak 5 min > final 5 min (P = 0.000); next 5 min < ave 5 min (P = 0.032)); and (C) acceleration counts in 5-min periods (peak 5 min > next 5 min (P = 0.000); peak 5min > ave 5 min (P = 0.000); peak 5min > final 5 min (P = 0.000); next 5 min < ave 5 min (P = 0.003); final 5 min < ave 5 min (P = 0.000)). Variables are peak 5 min during the game, the 5 min following the peak 5-min period, average 5 min during the game and the final 5 min of the game, with or without caffeine supplementation. Data are presented as means ± s.

AQ3

No differences were detected in peak speed between caffeine and placebo trials (28.4 ± 1.7 vs 28.4 ± 1.9 km · h^{-1}, d = 0 trivial, in the first half; and 27.9 ± 1.5 vs 28.3 ± 1.5 km · h^{-1}, d = 0.27 small, in the second half, respectively).

Post-game performance

Post-match Yo-Yo IR2 performance was almost identical in the caffeine and the placebo trial (caffeine: 829 ± 322 m, placebo: 819 ± 289 m, $P > 0.05$; Table I).

Blood glucose and lactate

The glucose level was higher ($P < 0.05$) in the caffeine trial than in the placebo group after first half (7.5 ± 2.1 vs 6.3 ± 1.6 mmol · L^{-1}, d = 0.64 moderate). After the second half, blood glucose levels tended ($P = 0.07$) to be higher in the caffeine trial (6.1 ± 0.7 vs 5.4 ± 0.4 mmol · L^{-1}, d = 1.23 large). Blood lactate increased in both groups ($P < 0.05$) from 1.6 ± 0.5 mmol · L^{-1} in the caffeine trial and placebo trials at rest, to 7.9 ± 4.8 and 6.1 ± 3.8 mmol · L^{-1} at half-time, and 5.5 ± 2.6 and 5.7 ± 2.9 mmol · L^{-1} at the end of the game. Higher ($P < 0.05$) blood lactate concentrations were detected in the caffeine trial at half-time. No between-trial difference was observed in blood lactate concentrations after the post-match Yo-Yo IR2 (Table II).

Heart rate and weight loss

Mean heart rate during match play was similar in the two trials ($P > 0.05$) being 166 ± 11 bpm in the caffeine trial versus 168 ± 8 bpm in the placebo trial, corresponding to 85.6% ± 3.7% and 86.1% ± 2.8% HR_{peak}. HR_{peak} was 192 ± 8 bpm in the caffeine group and 192 ± 5 bpm in the placebo group (Table I). Weight loss was 1.2 ± 0.6 kg independent of treatment, but the caffeine group consumed 0.5 ± 0.4 L more fluid compared to the placebo group ($P < 0.05$).

Discussion

The present study is the first to test the hypothesis that caffeine supplementation has an ergogenic effect during football match play in high-level young football players. The principal findings of the study were that caffeine intake did not change game activity profile or the degree of post-game fatigue. Both in the placebo trial and the caffeine trial, the players displayed similar fatigue patterns during and in the final stages of the game. Caffeine administration resulted in higher blood lactate and glucose levels after the first half and elevated the intake of water during the game, while no differences were observed in heart rate loading between experimental trials.

The physical loading, as observed in HR and lactate levels, and the degree of fatigue during the two games are comparable to studies of competitive high-standard games (Bangsbo, 1994; Bradley et al., 2009; Mohr et al., 2003), as well as experimental games (Krustrup et al., 2006; Mohr, Nybo, Grantham, Racinais, & Moran, 2012; Mohr et al., 2010). The average heart rate was ~85% of HR_{peak}, and blood lactate concentrations ranging 6–8 mmol · L^{-1} are of the same magnitude as observed previously (Bangsbo, Norregaard, & Thorso, 1991; Krustrup et al., 2006, 2010; Mohr & Krustrup, 2013; Mohr et al., 2010). Additionally, a marked decline was observed in high-intensity running during the last 15 min of the game as well as after the most intense 5-min intervals, which are similar to the findings for elite players (Bradley et al., 2009; Mohr et al., 2003) and reveal temporary fatigue during the game and fatigue at the end of a game. Thus, the physiological loading and fatigue development of the intervention matches appear to be as high as in competitive elite games.

In present study, the blood lactate and glucose concentrations were higher after the first half in the caffeine trial compared to placebo, as observed in other caffeine studies (Mohr et al., 2011). The higher blood glucose levels may indicate a larger catecholamine response, which may have multiple performance-enhancing effects relating to both central and peripheral mechanisms (Jones, 2008; Klass et al., 2012). For example, Na^+-K^+ ATPase activity

Table II. Blood glucose and lactate values (means ± *s*) with prior ingestion of placebo or caffeine in two football matches at rest, after warm-up, post first half and post second half as well as after the Yo-Yo IR2 test.

		Rest	Pre-game	Post first half	Post second half	Post Yo-Yo IR2
Glucose (mM)	Caffeine	5.6 (0.7)	5.6 (1.0)	7.5 (2.1)	6.1 (0.7)	
	Placebo	5.7 (0.7)	5.4 (0.5)	6.3 # (1.6)	5.4 (0.4)	
Lactate (mM)	Caffeine	1.6 (0.6)	4.6 (3.1)	7.9 (4.8)	5.5 (2.6)	9.5 (3.5)
	Placebo	1.6 (0.5)	3.9 (1.8)	6.1 # (3.6)	5.7 (2.9)	9.2 (3.7)

Note: # Denotes significant difference ($P < 0.05$) between placebo and caffeine (n = 21).

is stimulated indirectly by caffeine intake via an augmented catecholamine response (Clausen, 2003). Mohr et al. (2011) also demonstrated higher blood glucose levels after caffeine intake with concomitant improvement in muscle interstitial K^+ accumulation, which is acknowledged as a potential fatiguing mechanism during intense exercise (McKenna et al., 2008). The higher blood lactate concentrations after the first half of the game may therefore be interpreted as a reflection of higher contribution from anaerobic glycolysis to the energy turnover as a +consequence of improved fatigue resistance. In addition, the physiological effect of caffeine may be more pronounced during the first than the second half, since neither blood responses after the second half nor post the Yo-Yo IR2 were different between the two intervention trials. However, no differences were observed during the first half in any of the match performance variables, indicating no performance-enhancing effects of caffeine despite elevated blood glucose and lactate concentrations.

No differences were observed between the caffeine and the placebo trials in physical match performance indicators such as total distance covered, high-intensity running, sprinting and number of accelerations during the game. This is in contrast to the observations during simulated team sport trials (Stuart, Hopkins, Cook, & Cairns, 2005) and football-specific intermittent exercise protocols (Mohr et al., 2011), where a 16% caffeine-induced increase was shown. The lack of difference between the two trials is not likely to have been caused by inter-game variability, which can be large (Gregson et al., 2010). In order to reduce game-to-game variability of the present study, all game-related procedures and set-up were standardised except for the supplement intervention, meaning that the pre-game preparation, opponents, tactical approaches and playing formations as well as time of the match were the same for the two match days. Moreover, the use of a similar experimental game design has been shown to be sensitive enough to detect an effect of other types of interventions such as altered environmental settings (Mohr & Krustrup, 2013; Mohr et al., 2010; Özgünen et al., 2010). Finally, the activity measurements such as total distance covered, high-intensity running and sprinting performed, as well as heart rate response during the experimental games in the present study are comparable to other reports in high-level young football populations (Buchheit & Mendez-Villanueva, 2013; Castagna, Manzi, Impellizzeri, Weston, & Barbero Alvarez, 2010). Therefore, it is unlikely that the lack of caffeine-induced effect is due to a statistical type 2 error, although such a consequence cannot be conclusively ruled out.

The activity pattern in football is affected by numerous variables, such as physical fitness (Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005), competitive level (Mohr et al., 2003), surface (Andersson, Ekblom, & Krustrup, 2008), environmental temperatures (Mohr & Krustrup, 2013) as well as ball possession and technical standard (Bradley et al., 2013). Teams with a high technical ability and a possession-based playing type might not have to work as hard during games (Bradley et al., 2013; Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2009). In the present study, technical performances were not assessed, and therefore, players may have had an improved technical match performance in the caffeine trial. This has been demonstrated during more standardised settings such a simulated team-sport game trial (Stuart et al., 2005) and football-specific testing protocols (Mohr et al., 2011).

The players participating in the present study were ~17 years old, which may have played a role for the effect of caffeine. It is well known that the anaerobic capacity of young individuals is lower than of adults (Ratel, Duché, & Williams, 2006). Thus, the youngsters may not respond to caffeine to the same degree as shown in studies with adult participants (Graham, 2001; Mohr et al., 2011; Stuart et al., 2005). In addition, there may be responders and non-responders to caffeine as observed with other drugs (Wiley et al., 2012) and performance-enhancing strategies (Racinais et al., 2012). Figure 3 illustrates the percentage change in high-intensity running and Yo-Yo IR2 performance from the placebo to the caffeine game trial. In this study, high-intensity running and Yo-Yo IR2 performance were not correlated, which may

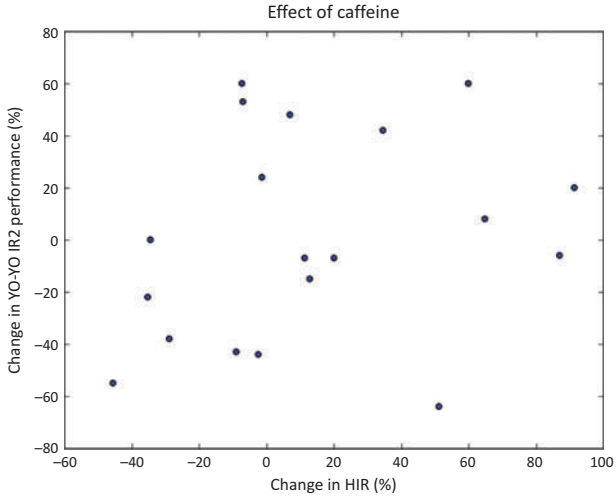

Figure 3. The percentage change in HIR as function of percentage change in Yo-Yo IR2. Individual values are presented.

partly be associated with different caffeine sensitivity.

The emphasis of supplements such as caffeine in elite sports has increased during the last decade, and effects on intense intermittent exercise capacity have been shown (Mohr et al., 2011; Stuart et al., 2005; Wylie et al., 2012). However, the performance effects from drug supplementation are markedly smaller compared to the adaptations demonstrated from exercise training (Mohr et al., 2007; Iaia et al., 2008, 2009), which calls for a critical approach when considering the use of supplements. In conclusion, the present study showed that caffeine intake does not alter the activity pattern and fatigue profile during match play for young male football players despite the physiological effects of caffeine supplementation.

Acknowledgements

The authors thank the players and their clubs Tromsoe IL and Tromsdalen UIL for the participation and excellent cooperation. The technical assistance by Susann Dahl Pettersen, Truls Hallen, Jorid Degerstrøm, Gunnar Mathisen and David Childs was appreciated.

Conflict of interest

There is no conflict of interest for any of the article authors.

References

Andersson, H., Ekblom, B., & Krustrup, P. (2008). Elite football on artificial turf versus natural grass: Movement patterns, technical standards, and player impressions. *Journal of Sports Sciences*, *26*, 113–122.

Bangsbo, J. (1994). Energy demands in competitive soccer. *Journal of Sports Sciences*, *12*, 5–12.

Bangsbo, J., Iaia, F. M., & Krustrup, P. (2007). Metabolic response and fatigue in soccer. *International Journal of Sport Physiology and Performance*, *2*, 111–127.

Bangsbo, J., Mohr, M., & Krustrup, P. (2006). Physical and metabolic demands of training and match-play in the elite football player. *Journal of Sports Sciences*, *24*, 665–674.

Bangsbo, J., Norregaard, L., & Thorso, F. (1991). Activity profile of competition soccer. *Canadian Journal of Sport Sciences*, *16*, 110–116.

Bendiksen, M., Pettersen, S. A., Ingebrigtsen, J., Randers, M. B., Brito, J., Mohr, M., … Krustrup, P. (2013). Application of the Copenhagen soccer test in high-level women players – locomotor activities, physiological response and sprint performance. *Human Movement Science*, *32*(6), 1430–1442.

Bradley, P. S., Carling, C., Gomez Diaz, A., Hood, P., Barnes, C., Ade, J., … Mohr, M. (2013). Match performance and physical capacity of players in the top three competitive standards of English professional soccer. *Human Movement Science*, *32*(4), 808–821.

Bradley, P. S., Sheldon, W., Wooster, B., Olsen, P., Boanas, P., & Krustrup, P. (2009). High-intensity running in English FA Premier League soccer matches. *Journal of Sports Sciences*, *27*, 159–168.

Buchheit, M., & Mendez-Villanueva, A. (2013). Supramaximal intermittent running performance in relation to age and locomotor profile in highly-trained young soccer players. *Journal of Sports Sciences*, *31*(13), 1402–1411.

Castagna, C., Manzi, V., Impellizzeri, F., Weston, M., & Barbero Alvarez, J. C. (2010). Relationship between endurance field tests and match performance in young soccer players. *Journal of Strength and Conditioning Research*, *24*(12), 3227–3233.

Clausen, T. (2003). Muscle K^+ Na^+ and CL disturbances and Na^+-K^+ pump activation: Implications for fatigue. *Physiological Reviews*, *83*(4), 1269–1324. Review.

Durnin, J. V. G. A., & Womersley, J. (1974). Body fat assessed from total body density and its estimation from skinfold thickness: Measurements on 481 men and women aged from 16 to 72 years. *British Journal of Nutrition*, *32*, 77–97.

Fitts, R. H. (1994). Cellular mechanisms of muscle fatigue. *Physiological Reviews*, *74*(1), 49–94. Review.

Gandevia, S. C. (2001). Spinal and supraspinal factors in human muscle fatigue. *Physiological Reviews*, *81*(4), 1725–1789. Review.

Ganio, M. S., Klau, J. F., Casa, D. J., Armstrong, L. E., & Maresh, C. M. (2009). Effect of caffeine on sport-specific endurance performance: A systematic review. *Journal of Strength and Conditioning Research*, *23*(1), 315–324.

Graham, T. E. (2001). Caffeine, coffee and ephedrine: Impact on exercise performance and metabolism. *Canadian Journal of Applied Physiology*, *26*(Suppl.), S103–S119. Review.

Hodgson, A. B., Randell, R. K., Jeukendrup, A. E., & Earnest, C. P. (2013). The metabolic and performance effects of caffeine compared to coffee during endurance exercise. *PLoS One*, *8*(4), e59561.

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*, 3–13.

Iaia, F. M., Hellsten, Y., Nielsen, J. J., Fernstrom, M., Sahlin, K., & Bangsbo, J. (2009). Four weeks of speed endurance training reduces energy expenditure during exercise and maintains muscle oxidative capacity despite a reduction in training volume. *Journal of Applied Physiology (1985)*, *106*(1), 73–80.

Iaia, F. M., Perez-Gomez, J., Nordsborg, N., & Bangsbo, J. (2010). Effect of previous exhaustive exercise on metabolism and fatigue development during intense exercise in humans. *Scandinavian Journal of Medicine & Science in Sports*, *20*(4), 619–629.

Iaia, F. M., Rampinini, E., & Bangsbo, J. (2009). High intensity running in football. *International Journal of Sports Physiology and Performance*, *4*(3), 291–306. Review.

Jeukendrup, A. E., & Randell, R. (2011). Fat burners: Nutrition supplements that increase fat metabolism. *Obesity Reviews*, *12*(10), 841–851.

Jones, G. (2008). Caffeine and other sympathomimetic stimulants: Modes of action and effects on sports performance. *Essays in Biochemistry*, *44*, 109–123. Review.

Klass, M., Roelands, B., Lévénez, M., Fontenelle, V., Pattyn, N., Meeusen, R., & Duchateau, J. (2012). Effects of noradrenaline and dopamine on supraspinal fatigue in well-trained men. *Medicine and Science in Sports and Exercise*, *44*(12), 2299–2308.

Krustrup, P., Mohr, M., Ellingsgaard, H., & Bangsbo, J. (2005). Physical demands during an elite female soccer game: Importance of training status. *Medicine and Science in Sports and Exercise*, *37*, 1242–1248.

Krustrup, P., Mohr, M., Nybo, L., Jensen, J. M., Nielsen, J. J., & Bangsbo, J. (2006a). The Yo-Yo IR2 test: Physiological

response, reliability, and application to elite soccer. *Medicine and Science in Sports and Exercise*, *38*, 1666–1673.

Krustrup, P., Mohr, M., Steensberg, A., Bencke, J., Kjaer, M., & Bangsbo, J. (2006b). Muscle and blood metabolites during a soccer game: Implications for sprint performance. *Medicine and Science in Sports and Exercise*, *38*, 1165–1174.

Krustrup, P., Ørtenblad, N., Nielsen, J., Nybo, L., Gunnarsson, T. P., Iaia, F. M., … Bangsbo, J. (2011). Maximal voluntary contraction force, SR function and glycogen resynthesis during the first 72 h after a high-level competitive soccer game. *European Journal of Applied Physiology*, *111*, 2987–2995.

Krustrup, P., Zebis, M., Jensen, J. M., & Mohr, M. (2010). Game-induced fatigue patterns in elite female soccer. *Journal of Strength and Conditioning Research*, *24*, 437–441.

Mendez-Villanueva, A., Buchheit, M., Simpson, B., & Bourdon, P. C. (2013). Match play distribution in youth soccer. *International Journal of Sports Medicine*, *34*(2), 101–110.

Mohr, M., & Krustrup, P. (2013). Heat stress impairs repeated jump ability after competitive elite soccer games. *Journal of Strength and Condition Research*, *27*(3), 683–689.

Mohr, M., Krustrup, P., Andersson, H., Kirkendal, D., & Bangsbo, J. (2008). Match activities of elite women soccer players at different performance levels. *Journal of Strength and Conditioning Research*, *22*, 341–349.

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. *Journal of Sports Sciences*, *21*, 519–528.

Mohr, M., Krustrup, P., & Bangsbo, J. (2005). Fatigue in soccer: A brief review. *Journal of Sports Sciences*, *23*, 593–599.

Mohr, M., Mujika, I., Santisteban, J., Randers, M. B., Bischoff, R., Solano, R., … Krustrup, P. (2010). Examination of fatigue development in elite soccer in a hot environment: A multi-experimental approach. *Scandinavian Journal of Medicine & Science in Sports*, *20*(Suppl. 3), 125–132.

Mohr, M., Nielsen, J. J., & Bangsbo, J. (2011). Caffeine intake improves intense intermittent exercise performance and reduces muscle interstitial potassium accumulation. *Journal of Applied Physiology*, *111*(5), 1372–1379.

Mohr, M., Nybo, L., Grantham, J., Racinais, S., & Moran, M. (2012). Physiological responses and physical performance during football in the heat. *PLoS One*, *7*(6), e39202.

Nybo, L. (2010). CNS fatigue provoked by prolonged exercise in the heat. *Frontiers in Bioscience*, *E2*(1), 779–792.

Özgünen, K. T., Kurdak, S. S., Maughan, R. J., Zeren, C., Korkmaz, S., Yazıcı, Z., … Dvorak, J. (2010). Effect of hot environmental conditions on physical activity patterns and temperature response of football players. *Scandinavian Journal of Medicine & Science in Sports*, *20*(Suppl. 3), 140–147.

Racinais, S., Mohr, M., Buchheit, M., Voss, S. C., Gaoua, N., Grantham, J., & Nybo, L. (2012). Individual responses to short-term heat acclimatisation as predictors of football performance in a hot, dry environment. *British Journal of Sports Medicine*, *46*(11), 810–815.

Rampinini, E., Impellizzeri, F. M., Castagna, C., Coutts, A. J., & Wisløff, U. (2009). Technical performance during soccer matches of the Italian Serie A league: Effect of fatigue and competitive level. *Journal of Science and Medicine in Sport*, *12*(1), 227–233.

Ratel, S., Duché, P., & Williams, C. A. (2006). Muscle fatigue during high intensity exercise in children. *Sports Medicine*, *36*(12), 1031–1065. Review.

Stuart, G. R., Hopkins, W. G., Cook, C., & Cairns, S. P. (2005). Multiple effects of caffeine on simulated high-intensity team-sport performance. *Medicine and Science in Sports and Exercise*, *37*, 1998–2005.

Tarnopolsky, M. A. (2010). Caffeine and creatine use in sport. *Annals of Nutrition and Metabolism*, *57*(Suppl. 2), 1–8.

Wylie, L. J., Mohr, M., Krustrup, P., Jackman, S. R., Ermıdis, G., Kelly, J., … Jones, A. M. (2013). Dietary nitrate supplementation improves team sport-specific intense intermittent exercise performance. *European Journal of Applied Physiology*, *113*(7), 1673–1684.