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CAFFEINE INTAKE ENHANCES ENDURANCE PERFORMANCE IN SUB-ELITE BUT NOT IN ELITE ATHLETES*

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ABSTRACT

The aim of our contribution is to evaluate the influence of caffeine (CAF) ingestion on maximal power output (MPO) during endurance performance. Two groups of men – 10 sub-elite cyclists and 8 elite cyclists completed a randomized, crossover, double-blind study. Over the course of three days participants completed three identical experimental tests (60min cycling time trial on 70 % VO_{2max} followed by test to exhaustion). Three experimental meals − a combination of 500ml water, a gel supplement and a specific dose of CAF: a placebo (PLA, no caffeine), CAF2 (2 mg / kg body weight (BW)) and CAF7 (7 mg / kg BW) were administered 45min prior to the start of the experimental tests. Subjective RPE values were determined using the Borg 20-category scale. The results show significant differences between MPO_{PLA} and MPO_{CAF7} and between MPO_{CAF2} and MPO_{CAF7} with p = 0.018 and p = 0.019, respectively, in the sub-elite cyclists group only. The mean MPO during experimental test in sub-elite cyclists, but not in elite cyclists, was significantly enhanced following caffeine ingestion (p = 0.05). These findings indicate that caffeine intake at recommended levels is not associated with improved performance in a professional level cyclist. The results of the comparison of the experimental situations using the Borg scale are not persuasive. We found a significant difference *(0.008356) between the PLA and CAF2 experimental measurements ($p < 0.05$). The level of substantive significance was assessed using Cohen's coefficient effect and only a small "size of effect" (0.19) was found. It is therefore not possible to determine whether the Borg scale might be used to define the effects of caffeine ingestion on endurance performance, due to the multifactorial effects of caffeine.*

Keywords: *caffeine, maximal power output, aerobic exercise, cycling*

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UŽIVANJE KOFEINA POVEČUJE VZDRŽLJIVOST PRI NEVRHUNSKIH ŠPORTNIKIH, NE PA PRI VRHUNSKIH

IZVLEČEK

Namen našega prispevka je oceniti vpliv zaužitega kofeina na maksimalno moč (MPO) v času vzdržljivostne vadbe. Na dveh skupinah, desetih nevrhunskih kolesarjev in osmih vrhunskih kolesarjev, je bila izpeljana randomizirana, navzkrižna, dvojna slepa študija. V treh dneh so udeleženci zaključili tri enake eksperimentalne teste (60 minut kolesarskega kronometra na 70 % VO_{2max}*, čemur je sledil preizkus izčrpanosti). Tri vrste eksperimentalnih obrokov − kombinacija 500 ml vode, dodatek gela in določen odmerek kofeina − so bile razdeljene med udeležence 45 minut pred začetkom eksperimentalnih testov, in sicer: placebo − PLA (brez kofeina), CAF2 (2 mg/kg telesne mase) in CAF7 (7 mg/kg telesne mase). Posamezne vrednosti RPE so bile določene s pomočjo Borgove lestvice dvajsetih kategorij. Rezultati kažejo na pomembne razlike med* MPO_{PLA} *in* MPO_{CAF7} *ter med* MPO_{CAF2} *in* $MPO_{CAF7,}$ *kjer sta vrednosti p = 0,018 in p = 0,019 zgolj v skupini nevrhunskih kolesarjev. Povprečna vrednost maksimalne moči se je med poskusnim testom po zaužitju kofeina znatno povečala (p = 0,05) samo pri skupini nevrhunskih kolesarjev. Te ugotovitve kažejo, da zaužitje kofeina znotraj priporočenih količin ne vpliva na večjo vzdržljivost vrhunskih kolesarjev. Rezultati primerjave eksperimentalnih testov z uporabo Borgove lestvice pa niso prepričljivi. Pomembno razliko (0,008356) smo zaznali med eksperimentalnima meritevama PLA in CAF2 (p < 0,05). Stopnja odločilnega pomena je bila določena s pomočjo Cohenovega koeficienta učinka in je bila ocenjena le kot majhen "obseg učinka" (0,19). Zaradi multifaktorskih učinkov kofeina zato ni mogoče ugotoviti, ali bi se s pomočjo Borgove lestvice lahko opredelilo vpliv zaužitega kofeina na vzdržljivost.*

Ključne besede: *kofein, maksimalna moč, aerobne vaje, kolesarjenje*

INTRODUCTION

It is evident that dietary supplements are becoming a part of an athlete's daily diet. The appropriate use and timing of dietary supplement intake may positively influence athletic performance and recovery. One of the most commonly used dietary supplements is caffeine (CAF). It is a natural component of many foods and beverages available to the general public. CAF is a stimulant that has a number of physiological and psychological effects. For this reason, it is widely used as a food supplement in the manufacture of sports nutrition. For many athletes, CAF is part of their dietary regime. Its application is found before or during competitions, and the training effect of CAF is dependent on its source, the adopted quantity dosage, one's sex, nutritional status and other factors related to each individual (Magkos & Kavouras, 2004). The influence of CAF on the human body is studied in relation to the possible improvement in sports performance. The body has a number of effects associated with a direct influence on performance – the stimulation of the central nervous system; an increasing cAMP and an influence on the activity of adrenaline are associated with increased lipolysis in adipose and muscle tissue, thereby increasing the availability of energy substrates to working muscles (Burke & Deakin, 2002). This glycogen sparing potential is not the only mechanism explaining the ergogenic effect of CAF. There is evidence of an increase in performance after CAF without affecting the oxidation of nutrients. It has been recently demonstrated, that CAF ingestion (3 mg/kg BW) is a possible strategy to independently enhance the power output of muscle glycogen availability (Lane et al., 2013).

Contemporary protocols for CAF intake on the day of training or competition are based on recent evidence showing that low doses of CAF (1−3 mg/kg BW) are as equally effective as the traditionally used larger doses (6−9 mg/kg BW) (Ganio et. al, 2009; McNaughton et al., 2008).

Within the context of potential ergogenic effects, CAF was tested many times, and has already been administered to athletes in many different sources such as chewing gum (Ryan et al., 2013), sports gels, Coca Cola, capsules and coffee (Jenkins et al., 2008; Cureton et al., 2007; Cox et al., 2002; Conway et al., 2003; Graham, 2001; Ganio et al., 2009).

The evidence for an ergogenic effect of CAF on high-intensity performance is scant compared to the data retrieved with endurance tasks. From a practical point of view, it must be noted, however, that the majority of performance-enhancing findings was generally verified in recreationally trained males. Whether the findings could be extrapolated to the elite athletes, remains unknown. Moreover, it is necessary that all evidence-based, though theoretical proposals and conclusions are clearly translated into the real training and / or competition practise. Therefore, the aim of our study is to find the variance between the two groups of athletes, each with a different training − fitness status.

MATERIALS AND METHODS

The research was precisely designed with respect to the CAF-supplement scientific trials. Ten male sub-elite cyclists and eight male elite cyclists (Table 1) completed the randomized, crossover, double-blind study. The sample group was divided into a sub-elite category and an elite category, according to the training volume (km per year, training hours per week) and the corresponding fitness status (VO_{2max}). The subjects were not allowed to participate in the study if they were smokers, took medications that might affect physical performance or metabolism, or lacked the ability to perform the initial laboratory maximal oxygen consumption tests (VO_{2max}). Before giving their written informed consent, every accepted participant became familiar with the possible negative consequences of all the procedures. The study was reviewed and approved by the Ethics Committee of the Faculty of Sports Studies.

Table 1: Characteristics of the elite and the sub-elite cyclists (Mean ± SD, range).

Parameters		sub-elite cyclists (n = 10)		elite cyclist (n = 8)		p
		Mean ± SD	Range	Mean ± SD	Range	
Age (years)		27.7 ± 4.1	22 – 35	23.5 ± 5.6	18 − 35	0.13
Height (cm)		181.4 ± 7.9	168 – 191	183.4 ± 5.5	174 − 194	0.52
Body weight (kg)		77.6 ± 8.0	68 – 92	76.4 ± 9.0	63 − 89	0.79
VO_2max. (ml / kg)		56.9 ± 6.6	50 – 67	66.4 ± 8.7	59 − 79	**0.02**
BMI (kg / m2)		23.6 ± 1.5	22 – 28	22.7 ± 1.8	21 − 26	0.51
FFM (kg)		68 ± 6.8	61 – 82	67.7 ± 7.6	57 − 79	0.95
Training volume*	(km / year)	5000 − 7000		18 000 – 22 000		**0.00**
	h / week	10 − 15		30 − 35		**0.00**

*Legend: BMI − body mass index, FFM − fat free mass, *expressed in terms of mean volume of training over the last 3 years.*

THE DESIGN OF THE EXPERIMENT

The experimental measurements were preceded by the incremental cycling test of exhaustion. Maximal oxygen consumption tests (VO_{2max}) were undertaken one week before the first experimental trial. The maximal test was used to determine the power output corresponding to 70 % of each subject VO_{2max} to be used in the experimental trials. During the three non-consecutive experimental days (within 1 month) the participants completed three identical experimental trials (60 min drive at the 70 % of VO_{2max} intensity followed by a test of exhaustion). All tests were completed on a software-controlled bicycle ergometer (Lode Excalibur *Sport*) using cardio metabolic unit Cortex MetaLyzer3B.

Three experimental liquid meals (a combination of 500 ml water, a gel supplement and a specific dose of anhydrous form of CAF): placebo (PLA, no caffeine), CAF2 (2 mg/kg BW) and CAF7 (7 mg/kg BW) were administered 45min prior to the start of the experimental tests. Time and maximal power output (MPO [Watts]) during the exhaustion phase of the experimental trials were measured. Rating of perceived exertion (RPE) was determined during the measurements at a 2-minute interval using the Borg scale (6−20).

Each participant obtained an individually adjusted specific pre testing carbohydrate–rich dietary protocol (8 g/kg BW/day). The athletes were asked to follow the dietary regime on the day preceding the experimental trials in order to eliminate the possible detrimental effects of the experimental measuring (i.e. substantive muscle glycogen reduction). Finally, the participants were given instructions about CAF-containing food and beverages and were asked to abstain from CAF ingestion at least 72 hours before the experimental measuring. Eventually, the participants were asked to record the real food intake, to detect any possible dietary mistakes.

STATISTICAL ANALYSIS

The data obtained was statistically analysed with the NCSS 9 software (Hintze, 2013) and presented as mean, standard deviation (SD) and range (minimum and maximum values). To determine the differences in MPO a t-test was used. The level of significance was set at the $p < 0.05$ level. A multi-factor analysis of variance (ANOVA) was used to examine the interactions within the whole group and the main effects using the RPE as a covariate. The level of substantive significance ("size of effect") was assessed using Cohen's *d* effect coefficient.

RESULTS

Results show significant differences (Table 2) between MPO_{PLA} and MPO_{CAF7} and MPOCAF2 and MPOCAF7 in the sub-elite group, but not in the elite ($p < 0.05$). The level of substantive significance was assessed using the Cohen's coefficient effect and was found to be middle and small "size of effect" (0.43 and 0.29). There was no significant effect of specific doses of CAF on MPO in the group of elite cyclist (Table 2).

Table 2: Maximal power output during (MPO) experimental trials and statistical analysis of the experimental trials within sub-elite and elite groups (p).

		Maximal power output (W)		p		
Experiment	Sample group	Mean ± SD	Range	MPO_{PLA} vs MPO_{CAF2}	MPO_{PLA} vs MPO_{CAF7}	MPO_{CAF2} vs MPO_{CAF7}
PLA	sub-elite	361.1 ± 24.7	325–404	0.459	**0.018**	**0.019**
CAF2		365.2 ± 26.7	332–422			
CAF7		372.9 ± 28.4	338–421			
PLA	elite	432.4 ± 44.0	360–480	0.444	0.863	0.803
CAF2		437.4 ± 48.9	381–494			
CAF7		434.5 ± 64.1	287–500			

Legend: PLA, placebo; CAF2, caffeine dose 2mg/kg/body weight; CAF7, caffeine dose 7mg/kg/body weight; MPO, maximal power output (W).

The result of ANOVA detected a statistically significant difference, as confirmed by Fisher's post-hoc LSD test. A statistically significant difference was found between PLA and CAF7 (Table 3).

Table 3: Statistical analysis of the RPE using the Borg scale.

Caffeine dose	p
PLA vs CAF2	0.352124
CAF2 vs CAF7	0.086538
PLA vs CAF7	**0.008356**

Legend: RPE, rate of perceived exertion; PLA, placebo; CAF2, caffeine dose 2mg/kg/body weight; CAF7, caffeine dose 7mg/kg/body weight.

Additionally, the level of substantive significance ("size of effect") was assessed in the sub-elite group using Cohen's *d* effect coefficient which shows the relative change of the average variable with respect to the standard deviation of measurements in the group. The difference between PLA and CAF7 situation is considered to be significant (Table 4).

Table 4: Statistical analysis of the RPE via the size of effect (sub-elite group).

	Cohen's *d*
PLA and CAF2	0.06
PLA and CAF7	**0.19**
CAF2 and CAF7	0.12

Legend: RPE, rate of perceived exertion; PLA, placebo; CAF2, caffeine dose 2mg / kg/body weight; CAF7, caffeine dose 7mg/kg/body weight.

DISCUSSION

Caffeine is a substance which is chronically integrated in sports dietary supplements. In 2004, CAF was erased from the list of banned substances, but currently it is still a substance listed as monitored (World Anti-Doping Agency, 2013).

There is ample evidence in the literature that CAF administered prior the exercise enhances performance (Cox et al., 2002; Ganio et al., 2009; Jenkins et al., 2008), however, the data where positive ergogenic effect of CAF dose on performance was not established is still available (Jacobson et al., 2001; Hunter et al., 2002). The contemporary research is dominantly carried out with sub-elite athletes. By incorporating a sub-group of elite (professional) athletes we tried to identify the possible superiority of dietary supplement intake in the context of various training statuses of the athletes. Therefore, we focused particularly on elite (professionally trained) athletes and made a comparison with sub-elite group**.** The overall size of the studied sample presented the limitation in the study. In particular, the number of elite-trained athletes willing to participate and mainly able to fully complete the experimental design was the main limitation. However, it must be noted that the number of professionally trained cyclists in the Czech Republic is rather small.

The primary aim of our specific research was to identify the variations in possible ergogenic effect of specific dose of CAF (0, 2 and 7 mg/kg BW) on MPO between sub-elite (well-trained) and elite (professionally trained) athletes. We chose a methodology that is standardized by a number of corresponding studies. Experimental cycling trial was performed ~ 60min after the oral CAF administration (Jenkins et al., 2008; Cureton et al., 2007; Cox et al., 2002).

The measured data (Table 2) demonstrate that the ingestion of CAF significantly increased MPO only in the sub-elite group (Table 3). The mean power output during the experimental test was enhanced following CAF ingestion (7 mg/kg BW) when compared with placebo (361.1 ± 24.7 vs. 372.9 ± 28.4 W, $p = 0.05$).

Furthermore, we found the dose response trend in sub-elite athletes. It must be noted that MPO was significantly enhanced both in CAF2 and CAF7 trial. It is assumed that the more CAF the well trained sub-elite (but not elite) athletes would ingest the better is their performance. However, a growing body of evidence currently suggests that moderate to low doses of CAF (~ 3 mg/kg BW) are effective at enhancing sport performance (Maughan, 2014).

Despite these facts we confirm the ergogenic influence of CAF intake on endurance performance consistently with the recent well-designed study of Lane et al. (2013), yet our findings are not consistent with several other recent studies. In the study of Ryan et al. (2012) the authors suggest that a low-dose CAF (200 mg) administered in chewing gum has no effect on cycling performance in recreational athletes (VO_{2max} 45.5 ± 5.7 ml/kg/min). Whether the form of CAF ingestion might modulate the performance outcome still remains to be established. In a study with well-trained athletes of similar fitness status (VO_{2max} 65.0 ± 6.3 ml/kg/min) and CAF ingestion (6 mg/kg BW) McNaughton et al. (2008) concluded that cycling performance was improved significantly.

There was no rationale for direct statistical comparison of sub-elite and elite group, since the main effect of CAF was only detected in the group of sub-elite cyclists.

Therefore, the training status (the general state of preparedness of an athlete, characterizing the current level of adaptation to the requirements of the relevant sports specialization – in our case, cycling performance) is assumed to be more important than the supplement of CAF. These findings indicate that CAF intake at both recommended (low) levels, i.e. 1−3 mg/kg BW and, moderate levels (6−9 mg / kg BW) previously thought to be ergogenic, is not associated with improved performance in professional level cyclist.

Finally, we focused on the possible effect of CAF intake on RPE. The results of the RPE analysis using the Borg scale are not convincing. Despite some differences between PLA and CAF7 experiments, there seems to be no rationale for using the Borg scale to differentiate the effects of various doses of CAF ingestion on endurance performance.

CONCLUSION

Despite the limited sample size we suggest that caffeine supplement represents a lower ergogenic benefit for professional (elite) athletes compared to the sub-elite.

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