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ORIGINAL INVESTIGATION

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Influence of caffeine, cold and exercise on multiple choice reaction time

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Abstract *Rationale:* The effects of caffeine on psychomotor performance have been evaluated under resting conditions and in a thermoneutral environment. Our hypothesis was that these effects could be modified by factors enhancing the level of alertness, such as exercise and cold exposure. *Objective:* The purpose of this study was to follow up changes in the multiple choice reaction time (RT) during exercise at room and low ambient temperatures after caffeine or placebo administered in a double blind manner. *Methods:* Nine soccer players performed multistage, incremental exercise until volitional exhaustion on a bicycle ergometer at 22°C or 4°C, 1 h after ingestion of coffee with caffeine (CAF) or without it (PL). Immediately before exercise and at the end of each workload, RT and blood lactate (LA) were measured. Oxygen uptake (VO_2) and heart rate (HR) were recorded continuously. Blood LA threshold and the workload associated with the shortest RT were determined. *Results:* During exercise at 22°C, RT was significantly shorter in CAF than in the PL test, while at 4°C there were no differences in RT between CAF and PL trials. Cold exposure did not affect RT either at rest or during exercise. Neither caffeine nor cold exposure influenced the maximal VO_2, the maximal HR and LA threshold. *Conclusion:* In the thermoneutral environment, caffeine ingestion improved psychomotor performance during exercise, whilst at low ambient temperature this effect was blunted. These findings suggest that the stimulating action of caffeine depends on the level and source of arousal.

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Introduction

Caffeine in the form of coffee is one of the most commonly used psychoactive and ergogenic agents. The effects of caffeine on psychomotor performance have been evaluated in several studies, and it was found that its ingestion increases vigilance (Fine et al. 1994), cognitive and psychomotor performance (Jacobson and Edgley 1987; Bryant et al. 1998; Durlach 1998; Robelin and Rogers 1998; Rees et al. 1999). The psychomotor response to caffeine was found to depend on age (Rees et al. 1999) and state of subjects including abstinence of caffeine prior to testing in coffee drinkers (James 1994) and presumably the level of alertness. Lorist et al. (1994) reported that stimulating effect of caffeine is more pronounced in fatigued than in rested subjects. Similarly, Rees et al. (1999) described improvements in vigilance and psychomotor performance by caffeine in elderly subjects who felt less alert later in the day.

The arousal level can be modified by environmental factors and the subjects' physical activity. Previous data indicated that exercise of low or moderate intensity improves psychomotor performance, which can be attributed to enhanced alertness (Levitt and Gutin 1971; Sjöberg 1975; Bula and Chmura 1984; Chmura et al. 1994, 1998; Travlos and Marisi 1995; Ziemba et al. 1999). In contrast, during heavy exhaustive exercise, psychomotor performance deteriorates (Bender and McGlynn 1976; Chmura et al. 1994; Ziemba et al. 1999). It was also reported that moderate (non-hypothermic) cold exposure increases arousal which was evidenced by shortening of latencies of evoked potentials (Van Orden et al. 1990). It is not known, however, whether modifications of the arousal level, caused by exercise or cold exposure, affect psychomotor response to caffeine. An answer to this question may be of practical importance since coffee is often used by athletes exercising in a cold environment.

The aim of this investigation was to find out whether ingestion of caffeine in the form of instant coffee exerts any influence on psychomotor performance during exercise and if so, whether this influence depends on thermal conditions under which the exercise is performed. Therefore, we have followed up changes in the multiple choice reaction time during graded incremental exercise performed by the same subjects at 22°C and 4°C after caffeine or placebo administered in a double blind manner.

Material and methods

Subjects

Nine healthy male soccer players, members of the Polish 3rd league team [age: 19.7±2.6 (SD) years, height: 179.1±3.5 cm, weight: 71.9±7.2 kg], participated in this study after giving their informed consent. Before the investigations the subjects consumed coffee only occasionally (1–2 times per month). The study protocol was approved by the Ethics Committee at the Medical Research Centre, Polish Academy of Sciences in Warsaw.

Experimental procedure

The subjects, familiarized with the laboratory conditions and testing procedure, were asked to limit their physical activity and abstain from coffee consumption for 24 h prior to testing. All the trials were conducted at the same time of the day. Each subject reported to the laboratory on four occasions separated by approximately 1 week. The subjects ingested instant coffee with 5 mg/kg caffeine or caffeine-free coffee in a double blind manner, and then rested for 60 min at a comfortable ambient temperature. After the resting period, the subjects dressed in shorts, T-shirts and jogging shoes performed, in randomized order, graded incremental exercise tests either at an ambient temperature of 4°C (70% relative humidity) or at 22°C (60% relative humidity), in a temperature and humidity-regulated chamber. The exercise tests were performed on a bicycle ergometer (Siemens, Germany), with a load increasing by 50 W every 3 min until volitional exhaustion, starting from 50 W at 60 revolutions per min. Exercise loads were separated by 30-s rest intervals, for taking blood samples from the fingertip for lactate (LA) determination. Ten minutes after entering the thermal chamber, the choice reaction time (RT) measurements were performed at rest immediately prior to exercise, and then during the last 2 min of each exercise load. Heart rate (HR) and oxygen uptake (VO_2) were recorded continuously throughout all exercise tests using Sport Tester PE 3000 (Polar Electro, Finland) and MedGraphics system (USA), respectively.

Multiple choice RT measurements

In order to determine RT during exercise, the multiple choice RT console was mounted on the wall in the front of the ergometer at eye level, 1.5 m away from the subjects. The RT test included 15 positive signals (red light or a sound) and 15 negative (green and yellow lights) stimuli applied in random order. The subjects were asked to press and then to release, as quickly as possible, the button on the right handlebar of the bicycle ergometer in response to the red light, the button on the left handlebar in response to the sound and do not react to the negative stimuli. During familiarization with the procedure, before starting the study, the subjects practiced the task until no errors were made. Total time for the RT trial was 107 s. The stimuli and the subjects' responses were recorded using the RT measuring device (MRK 432 Zabrze, Poland). Reaction time was determined to the nearest 0.01 s. The results are presented as the mean value of 15 responses to the positive stimuli at rest and at each exercise load. During each exercise test the workload (WL in watts) at which RT was the shortest was detected.

Analytical methods

Blood lactate concentration was determined enzymatically using commercial reagent sets (Boehringer Diagnostica, Mannheim, Germany). The LA threshold (LAT) was calculated for each subject using a log-log transformation method of Beaver et al. (1985). The threshold workload expressed in watts was assessed from the intersection of the two linear segments of log LA plotted versus log exercise load.

Statistics

The data are presented as means with standard errors (SE). Significance of temperature (4°C and 22°C) or drug (caffeine or placebo) effects within each workload were analyzed by 2×2×7 ANOVA for repeated measures. Paired Student's *t*-test was used for the post hoc analysis in the event of a significant *F* ratio. Statistical significance was assumed for $P<0.05$.

Results

Psychomotor performance

Accuracy of responses in neither test was affected by exercise until maximal work load when few subjects made one or two errors. In further calculations only the time of reaction was taken.

Thermoneutral conditions

Analysis of variance revealed significant differences in RT values between the subjects performing the tests with caffeine (CAF) and placebo (PL) at 22 °C ($P<0.01$). As shown in Fig. 1 the RT was significantly shorter during CAF than during PL test at 100, 150 and 200 W. Thereafter the RT started to increase in both tests, although the increase was less pronounced in the CAF than in PL test. The mean exercise loads at which the shortest RT values were achieved are given in Table 1. These loads corresponded to 70±1.4% and 64.4±1.8% of VO_2max in CAF and PL tests, respectively ($P>0.05$). During the CAF test, RT at the maximal workload exceeded by 45.3±8.9 ms the pre-exercise value ($P<0.01$) and by 86.6±10.8 ms the RTminim ($P<0.01$). During the PL test, RT at the maximal load was by 64.4±28.4 ms longer than the resting value ($P<0.05$) and by 81.2±28.9 ms ($P<0.02$) than the RTminim.

Cold environment

Analysis of variance did not show any significant effect of low ambient temperature on RT values during exercise ($P>0.05$). No differences were found in RT values between the CAF and PL tests at 4°C ($P>0.05$). During

Table 1 Mean values (±SE) of maximal oxygen uptake (*VO_2max*), maximal heart rate (*HRmax*), lactate threshold (*LAT*), the shortest reaction time (*RTminim*) and the workload (*WL*) at which RTminim occurred during graded, incremental exercise performed at 22 and 4°C after placebo or caffeine ingestion

Variable	Placebo		Caffeine	
	22°	4°C	22°C	4°C
VO_2max (l·min^{-1})	3.95±0.06	4.21±0.11	4.25±0.16	4.21±0.09
HRmax (beats^{-1})	195±2.4	190±1.9	193±1.9	196±3.1
LAT (W)	183.4±7.8	167.6±11.3	189.7±8.6	172.3±11.3
RTminim (ms)	294±8	278±9	272±7**	270±10
WL (W)	177.7±8.8	183.3±14.4	188.9±7.3	193.4±15.4 ^{x}

** Denotes significance of difference in RTminim between CAF and PL tests at 22°C (*P*<0.01)
^{x} Denotes a significant difference between WL and LAT

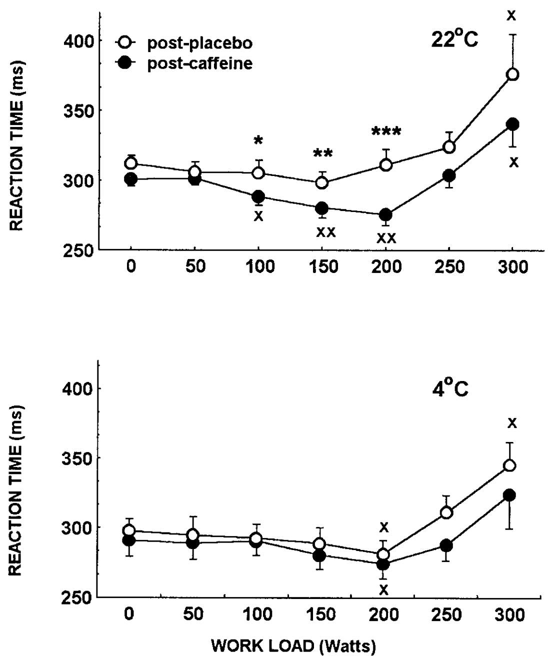

Fig. 1 Effect of caffeine on multiple choice reaction time during incremental exercise at two different ambient temperatures. The data are means (±SE). *Asterisks* denote significant differences between caffeine and placebo tests (**P*<0.05; ***P*<0.01; ****P*<0.001), *crosses* denote significant differences between resting and exercise values (^{x}P<0.05; ^{xx}P<0.01)

submaximal exercise loads in the cold environment there were practically no changes in RT below 200 W, either in CAF or PL tests (Fig. 1). At 200 W RT values were lower than at rest (*P*<0.05) in both tests. Above this exercise intensity, RT started to increase. The mean exercise loads at which the shortest RT values were achieved at 4°C are presented in Table 1. These loads corresponded to 70±1.2% and 70.4±0.9% of VO_2max in CAF and PL tests, respectively (*P*>0.05). In the PL test, the RT at the maximal work load exceeded by 47.7±20.0 ms the pre-exercise value (*P*<0.05) and by 64.1±19.4 ms the RT minim. (*P*<0.01). In the CAF test, the differences were 33.3±27.0 ms (*P*>0.05) and 50.2±22.7 ms (*P*>0.05), respectively.

Physical performance

As shown in Table 1, the maximal oxygen uptake (VO_2max) and the maximal heart rate (HRmax) were not affected significantly either by caffeine or thermal conditions. The lactate threshold (LAT) tended to occur at lower work intensity at 4°C than at 22°C but there were no differences in LAT between CAF and PL trials. Only in the cold-CAF test the exercise load at which the shortest RT appeared was above the LA threshold (*P*<0.05). In the remaining tests the RTminim occurred at exercise loads similar to those of LAT.

Discussion

The new finding of this study is that in thermoneutral environment (22°C) caffeine ingestion improves psychomotor performance during exercise, whilst at low ambient temperature this effect is blunted. The pattern of changes in the multiple reaction time (RT) during exercise was similar to that previously described in this laboratory by Chmura et al. (1994), and Ziemba et al. (1999). It was confirmed that during graded, incremental exercise till exhaustion, the multiple reaction time (RT) decreases below resting values at low and moderate work intensities, while further increases in exercise intensity cause deterioration of psychomotor performance. Chmura et al. (1994) demonstrated that the shortest reaction time occurs at exercise loads slightly above the blood lactate and plasma catecholamine thresholds. After exceeding these thresholds there is a rapid increase in blood lactate concentration, which is accompanied by muscle fatigue. The decrement of the psychomotor performance at high exercise intensities may indicate development of central fatigue (Chmura et al. 1994).

Caffeine ingestion did not affect RT measured immediately before exercise. The lack of the caffeine effect may suggest that emotional arousal, induced by anticipation of exercise, inhibited the stimulating action of caffeine. During exercise at 22°C, the RT shortening was significantly more pronounced after caffeine than placebo. Moreover, the shortest RT values were significantly lowered by caffeine. These findings indicate that caffeine facilitates achievement of the level of exercise-induced arousal, which is optimal for psychomotor performance. It has been proposed that the performance enhancement (James 1994), as well as an increase in cerebral blood flow velocity and changes in electroencephalography activity (Jones et al. 2000) after coffee ingestion, reflects the removal of the withdrawal effects seen after placebo. However, the subjects participating in the present study drank coffee only occasionally, so the shortening of RT after coffee ingestion seems to be attributable to caffeine stimulating action per se.

Taking into account that cold exposure accelerates processing of sensory stimuli in the central nervous system (Van Orden et al. 1990), it might have been expected that it would shorten RT at rest and during exercise. But this was not the case when the overall effect of cold on RT in the placebo tests was considered. Only tendencies towards shorter RT values were noted at high work intensities at 4°C compared with 22°C, and the RTminim value in the cold tended to be lower than at room temperature. It cannot be excluded that cold exposure might influence adversely the motor component of the choice reaction by diminishing hand muscle contractility (De Ruiter and De Haan 2000), although the contribution of movement time to the total reaction time is rather small. Another factor which could affect psychomotor performance is distraction caused by cold sensation.

Caffeine ingestion prior to exercise in the cold did not affect the course of changes in RT during exercise. The reason for the lack of caffeine effect in the cold is not clear. It can be speculated, however, that the cold-induced arousal inhibits the stimulating effect of caffeine on the central nervous system (CNS) similarly as the emotional arousal. It follows that not only the level of arousal but also its source may be important when the relationship between the caffeine action on CNS and the subject's state is considered. A dissociation between the effects of emotional and exercise-induced arousal has been previously demonstrated in the studies concerning memory (Libkuman et al. 1999).

Caffeine ingestion did not influence VO_2max significantly in either environmental condition, but the LA threshold tended to be shifted to the lower exercise intensities in the cold environment, both after caffeine and placebo (Table 1). The latter finding confirmed the suggestions of Bergh (1980) and Kruk et al. (1989), that body cooling decreases the muscle working capacity. The lack of effect of caffeine on the LA threshold during incremental exercise performed in the cold was also reported in our previous study (Kruk et al. 2000).

Shifting of the LA threshold towards lower workloads in the cold promotes earlier development of muscle fatigue under this condition. The workloads associated with the shortest reaction time were close to the LA thresholds at 22°C but they occurred at higher work intensities than the LA threshold at 4°C, although the difference was significant only after caffeine. Therefore, it could be suggested that impairment of psychomotor performance at high exercise loads is not directly related to the peripheral mechanisms of fatigue.

In conclusion, caffeine ingestion shortened the choice reaction time during exercise performed in a thermoneutral environment, but not at low ambient temperature. These findings have some practical implications for men exercising in cold and they also suggest that in the studies concerning the effects of caffeine on psychomotor function attention should be paid to the subjects' physical activity and environmental conditions.

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