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ORIGINAL ARTICLE

Ergogenic effects of the combination of caffeine and New Zealand blackcurrant supplements on time trial: A double-blind single-case experimental study

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ABSTRACT

The use of single supplements to enhance performance is widespread among athletes. The aim of this study was to increase knowledge about the combined effects of caffeine and New Zealand blackcurrant (NZBC) dietary supplements. In this counterbalanced alternating treatment single-case design, two participants each underwent four phases of four sessions in a double-blind, randomized order. After a 3-week pre-test phase, the supplement combinations of placebo/placebo, caffeine/placebo (5 mg/kg), NZBC/placebo (600 mg), and caffeine/NZBC (5 mg/kg + 600 mg) were taken and weekly performance tests were conducted to examine their effects on relative power (W/kg) during a 20-minute time trial on a bicycle. Data were analyzed descriptively and using the Tau-U calculator from Single Case Research. The ergogenic effect of caffeine was confirmed in both participants, with increases of 3.3% and 6.5%, while the positive effect of NZBC on performance was only seen in one participant (13.4%). The combination of caffeine and NZBC again increased performance in both participants (2.2% and 19.2%), but the data only showed a near additive effect of the supplements in one participant. The participants did not show a consistent performance improvement with the combined intake of the supplements caffeine and NZBC. Further studies are required to confirm or refute this evidence of the synergistic effects of these supplements.

Keywords: Sport medicine, Sport nutrition, Ergogenic aid, Endurance, Time trial, Caffeine, New Zealand blackcurrant.

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INTRODUCTION

Supplements with supposed performance-enhancing effects are widely used by athletes; however, only a few have been shown to have clear effects on athletic performance (Castell, Stear, & Burke, 2015). Two very prominent supplements are caffeine (Grgic, Grgic, et al., 2020) and New Zealand blackcurrant (Braakhuis, Somerville, & Hurst, 2020). However, to the best knowledge of the authors possible interaction effects of these supplements have not been analysed so far.

Caffeine is studied in numerous endurance- and strength-based sports and tests. An umbrella review showed that it had ergogenic effects on, among other things, aerobic endurance (Cohen's d = 0.22-0.61) and muscle endurance (d = 0.28-0.38) (Grgic, Grgic, et al., 2020). With regard to the present study, a time-dependent effect on aerobic endurance with Cohen's d of 0.25 can be expected (Shen, Brooks, Cincotta, & Manjourides, 2019). Caffeine can have a positive effect on athletic performance by reducing the signs of fatigue through inhibition of adenosine binding in the central nervous system and increasing the rate of muscle contraction (Davis et al., 2003; Shen et al., 2019) when a dose of at least 3 mg/kg body weight is ingested between 30 and 90 min before exercise (Southward, Rutherfurd-Markwick, & Ali, 2018).

New Zealand blackcurrant (NZBC) contains a large amount of polyphenols, specifically anthocyanins, which have been shown to have a small but significant standardized mean percent effect of 0.45 on cycling or running performance (Braakhuis et al., 2020). One study found that cycling performance improved when a dose of 300-600 g NZBC extract (containing 105-210 mg anthocyanins) was taken before exercise for seven days (Cook, Myers, Blacker, & Willems, 2015). This increase in performance could be explained by improved blood flow (Cook, Myers, Gault, & Willems, 2017) and reduced oxidative stress (Currie et al., 2022) as anthocyanins increase nitric oxide in endothelial cells and reduce the degradation of nitric oxide by free radicals (Edirisinghe, Banaszewski, Cappozzo, McCarthy, & Burton-Freeman, 2011).

Consequently, synergistic effects could occur when these two supplements are combined. Caffeine helps physical fatigue to occur more slowly because it blocks the adenosine receptors in the body (Cormano, Redondo, Rogel, & Bach-Faig, 2020). At the same time, with the release of free fatty acids (Gutiérrez-Hellín et al., 2023) and increased blood flow (Cook et al., 2017), the combination of caffeine and NZBC could result in lower anaerobic glycolysis activity and consequently lower lactate levels due to the improved supply to working muscles. The extent to which the combination of caffeine and NZBC supplements can lead to improved performance compared to using the supplements in isolation has only been investigated in one study (Paton, Morton, Bomal, & Braakhuis, 2022). Those findings showed that cycling performance over 8 x 5-minute maximal intensity intervals showed no significant differences in the variables of power output, heart rate, oxygen consumption, muscle oxygen saturation, and rating of perceived exertion between the placebo and supplement conditions (all $p > .05$). Since the primary aim of the study was to investigate the effects of acute NZBC supplementation (Paton et al., 2022), but so far only ergogenic effects have been reported with chronic supplementation over seven days, the answer about synergistic effects of both supplements remains open. Therefore, the purpose of this study was to extend the previous findings on the combined effects of these two supplements using a chronic supplementation protocol for NZBC.

METHODS

Participants

The study included two males who were recruited via personal contact. The inclusion criteria were unrestricted resilience (no complaints of the musculoskeletal system and the cardiovascular-respiratory system) and sufficient experience in cycling.

The anthropometric data of the participants are presented in Table 1. Participant A is a mountain biker who regularly competes and can be classified as a competitive cyclist. Participant B is a recreational athlete who regularly participates in bike tours and uses a bike in everyday life but does not compete in competitions.

The study was conducted according to the Declaration of Helsinki (World Medical Association, 2013) and the combination of supplements was approved by the Ethics Committee of the RPTU Kaiserslautern-Landau (2020/55) on 20.05.2020.

Table 1. The anthropometric characteristics of the participants A and B.

Variable	**A**	**B**
Sex	m	m
Age (years)	25	32
Body height (cm)	181.5	187
Body weight (kg; Mean ± SD)	77.5 ± 0.8	90.5 ± 3.3
Skeletal muscle mass (kg; Mean ± SD)	38.8 ± 0.6	45.1 ± 1.1
Leg lean mass (kg; Mean ± SD)	20.5 ± 0.2	24.3 ± 0.6
Body Fat (%; Mean ± SD)	12.2 ± 0.5	13.0 ± 3.0
Assessment category for PWC-Power at the beginning (W/kg)[1]	+	+
Assessment category for PWC-Power at the end (W/kg)[1]	++	+++

[1] Classification of the PWC_{150} performance into the assessment categories -, Ø, +, ++, +++ (Ferger & Büsch, 2018).

Design

An alternating-treatment single-case design was selected to demonstrate the effects of the interventions due to its methodological advantages, since the tests at the group intervention level caused high equipment, financial, and time requirements. In addition, there was the difficulty of acquiring participants for a group intervention, as the study significantly interfered with normal training practice. Furthermore, a single-case design seemed methodologically advantageous because high intraindividual differences in the effects of caffeine supplementation have been reported, which could be accounted for by using this design (Pickering & Kiely, 2018). The study began with an initial pre-test phase of three sessions in January. Subsequently, the participants each underwent four cycles of four phases until May (participant B) respectively July (participant A):

- Baseline phase (BL), during which the participants ingested placebo caffeine and NZBC capsules;
- Caffeine phase (CAF), during which the participants took caffeine capsules and placebo NZBC capsules;
- New Zealand blackcurrant phase (NZBC), during which the participants ingested NZBC capsules and placebo caffeine capsules;
- Caffeine und NZBC phase (ALL), during which the participants ingested caffeine and NZBC capsules.

The order of the phases within the cycles was counterbalanced. Each phase lasted one week and contained one session. The measurements in each of the approximately 90-minute sessions were 7 days apart. The sessions took place on the same day at the same time for both participants. The order of the phases for each participant was determined in advance of the study (Table 2).

Due to breaks caused by illness, it was not possible for both participants to complete the phases as planned. Therefore, the measurements were resumed after the subjects' self-assessment and the measurement phase was extended in order to compensate missed sessions after the last measurement. Consequently, the counterbalanced test protocol could not be fully realized.

Interventions

The caffeine supplementation was achieved using capsules (Fitmart GmbH & Co. KG, Elmshorn, Germany), which was adjusted to a dose of 5 mg/kg body weight. The caffeine placebo consisted of equal amounts of

microcrystalline cellulose. The caffeine and placebo capsules were taken 1 hour before each session on the day of the test (Southward et al., 2018).

Table 2. The sequence of the different phases.

Week	Planned phase
1	Pre-test (no supplementation)
2	Pre-test (no supplementation)
3	Pre-test (no supplementation)
4	Caffeine (CAF)
5	Caffeine + New Zealand Blackcurrant (ALL)
6	New Zealand Blackcurrant (NZBC)
7	Placebo (BL)
8	Caffeine + New Zealand Blackcurrant (ALL)
9	New Zealand Blackcurrant (NZBC)
10	Caffeine (CAF)
11	Placebo (BL)
12	New Zealand Blackcurrant (NZBC)
13	Caffeine (CAF)
14	Caffeine + New Zealand Blackcurrant (ALL)
15	Placebo (BL)
16	Caffeine (CAF)
17	Caffeine + New Zealand Blackcurrant (ALL)
18	New Zealand Blackcurrant (NZBC)
19	Placebo (BL)

The NZBC supplementation was also achieved using capsules (CurraNZ®, Health Currancy Ltd, Camberly, Great Britain), which contained 300 mg of NZBC extract. The manufacturer (CurraNZ®) also supplied the microcrystalline cellulose placebo capsules, which were identical in appearance and quantity. The participants took two capsules each for 7 days. Prior to the test days, the capsules were taken at breakfast and on the test days, they were taken 2 hours prior to the tests (Cook et al., 2015).

Depending on the phase, the supplement and placebo capsules were combined so that the same number of capsules were taken in each phase. The supplement capsules were prepared in advance of the study by an independent person who was not involved in the measurements. The participant-specific doses for each week were packed into bags so that the study could be conducted in a double-blind manner. The investigators received the labelled bags and passed them on to the participants according to the current test week.

Procedure

Before each test, the participants were instructed to have an identical breakfast, not to consume caffeinated foods or beverages for 48 hours, not to consume alcohol or polyphenol-rich foods or beverages for 24 hours, and not to perform intensive exercise for 24 hours. The endurance tests were performed using a Cyclus2® ergometer (RBM elektronik-automation GmbH, Leipzig, Germany) so that both participants could complete all tests on their own road bike with their own individual settings. Before the start of the study, the participants' positions on their bikes were checked according to common practice (Bartaguiz, Dindorf, Dully, Becker, & Fröhlich, 2022).

On the first day of testing, height and weight of the participants were measured and a bioimpedance analysis (BIA) was performed to determine their body compositions. The BIA was repeated regularly over the data collection period.

At the beginning of each testing session, the participants' resting blood pressure and heart rate were measured. After this, the participants completed the Short Recovery and Stress Scale for Sports (SRSS) questionnaire (Kellmann & Kölling, 2019) and the physical work capacity 150 (PWC_{150}) test to warm up and check their current aerobic performance capacity. During the test, the participants' heart rates were measured. The participants were allowed to select an individual cadence for the first measurement, which was then fixed for all subsequent measurements. At the end of the PWC_{150}, the rating of perceived exertion (RPE) was determined by the participants. The PWC_{150} was followed by a 10-minute recovery period at 100 W, which was also at a self-selected cadence. During the last 2 minutes of recovery, a portable metabolic system was attached to the participants and coupled with the Cyclus2® ergometer. Subsequently, the participants completed a 20-minute time trial (TT), during which the highest possible power output was to be achieved over time. The participants were allowed to select their wattage and cadence independently (Sitko, Cirer-Sastre, Corbi, & López-Laval, 2020). The power-related data were not blinded.

Measures

During the study body weight (kg), proportional skeletal muscle mass (kg), fat mass percentage (%), the ratio of extracellular to total body water, and lean leg mass (kg) were measured using a BIA (InBody770, InBody Europe, Eschborn, Germany). Resting systolic (sBP; mmHg), diastolic blood pressure (dBP; mmHg) and resting heart rate (rHR; bpm) were measured three times after 10 minutes of rest in the supine position on a yoga mat (Tensoval® comfort, Paul Hartmann AG, Heidenheim, Germany; Polar H10, Polar Electro Oy, Kempele, Finland) and then the mean value was calculated. The athletes' recovery and stress status were measured using the SRSS with Cronbach's α = 0.78-0.84 (Kellmann & Kölling, 2019). During the PWC_{150}, which has a reliability of r = 0.78 (McArdle, Katch, Pechar, Jacobson, & Ruck, 1972), the relative power (PWC-Power; W/kg) was measured, starting with a power of 100 W and increasing by 25 W every 2 minutes. After the PWC_{150}, the participants' exertion (RPE_{150}) was determined using a valid Borg scale ($r \approx 0.6$) (Chen, Fan, & Moe, 2002). For spiroergometric measurement during TTs, the K5 device (COSMED® S.r.l., Rome, Italy) with breath-by-breath method was used, which reproduces data with less than 2% deviation (Winkert, Kamnig, Kirsten, Steinacker, & Treff, 2020). Studies have also confirmed the reproducibility of power output in 20-minute TTs (r = 0.98) (Nimmerichter, Williams, Bachl, & Eston, 2010). Relative power normalized by weight (primary outcome variable) for better comparability (TT-Power; W/kg) and the variables RPE, average (HR_{mean}; bpm) and maximum (HR_{max}; bpm) heart rate, respiratory exchange ratio (RER), oxygen volume (VO_2; ml), and carbon dioxide volume (VCO_2; ml) were measured at minutes 5, 10, 15, and 20 as secondary outcomes.

Analysis

All data were graphed for each participant using Excel 2019 (Microsoft, Redmond, WA, USA) and each phase was visually analysed (Kratochwill et al., 2013). In the visual inspections, we examined changes within and between phases to identify trends, changes in level or stability (criterion fulfilled when 85% of the data in a phase fall within a 15% range of the median of all data points for that phase), and overlaps between the BL and CAF, NZBC, or ALL phases (Lobo, Moeyaert, Baraldi Cunha, & Babik, 2017). To facilitate this visual analysis, a line was mapped for the median values of all sessions within each phase. The Tau-U calculator from Single Case Research (http://singlecaseresearch.org/calculators/tau-u) was used to determine the trends within each phase, any contrasts between the phases, and the combined analysis of both participants.

RESULTS

Recovery and Stress perception

The weekly questionnaire on the recovery and stress states of the participants only showed small variations between the phases (Figure 1) and the calculated contrasts showed no significant differences (all $p > .05$). Consequently, it was assumed that the physical conditions were the same on all measurement days.

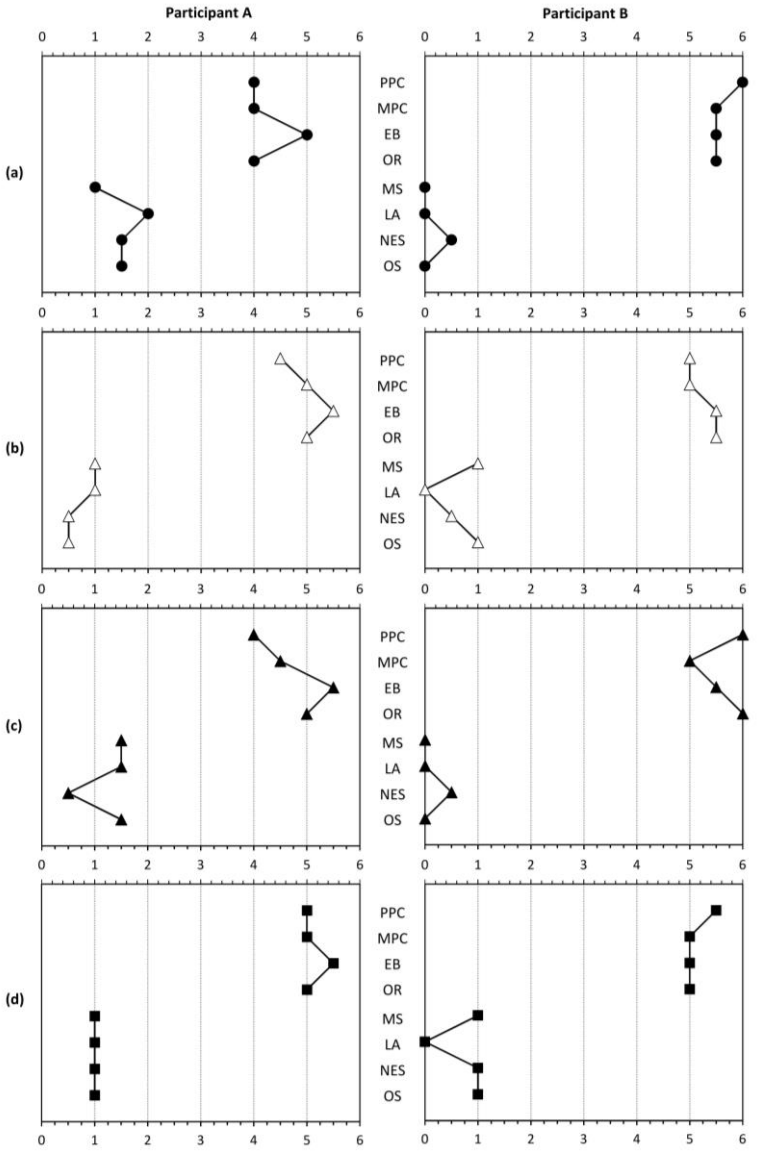


Figure 1. The median results of the Short Recovery and Stress Scale for Sports with the two dimensions Recovery (PPC, physical performance capability; MPC, mental performance capability; EB, emotional balance; OR, overall recovery) and Stress (MS, muscular stress; LA, lack of activation; NES, negative emotional state; OS, overall stress) for subjects A and B across the four phases: (a) baseline phase; (b) caffeine phase; (c) New Zealand blackcurrant phase; (d) caffeine + New Zealand blackcurrant phase.

Physiological and performance parameters

Stability

The characteristics of the participants in the BL phase were considered stable at 75-100% (Tables 3 and 5). Only the rHR variable for participant B showed a lower stability of 50%.

In the treatment phases, participant A showed the same stability across all variables, with only the rHR variable showing lower stability (50%) in the CAF and ALL phases (Table 3). For participant B, the lowest stability was observed at 50% for sBP (CAF), rHR (NZBC), and PWC-power (CAF, NZBC). However, as in the BL phase, there was an overall high stability of at least 75% (Table 5).

Table 3. The median results of the resting values, the physical working capacity test, and the time trial for participant A.

Level	BL	CAF	NZBC	ALL
		Resting Parameters		
sBP (mmHg)	123	128	127.33	129
dBP (mmHg)	64	74*	65.83	72*
rHR (bpm)	57	57	60	57
		Physical Working Capacity Test (PWC_{150})		
PWC-Power (W/kg)	2.91	2.87	2.96	2.82*
RPE_{150}	16	14.5	15	14.50*
		Time Trial (TT)		
TT-Power (W/kg)	3.57	3.72*	3.51	3.68
HR_{mean} (bpm)	168	176*	168	175*
HR_{max} (bpm)	178	186*	180	187*
RER	0.85	0.83	0.88	0.84
VO_2 (ml)	4995	5219	4520*	5095
VCO_2 (ml)	4172	4340	3962	4300
		RPE		
After 5 min	17	16.5	16.5	17
After 10 min	17.5	17.5	17.5	18
After 15 min	19	19	18.5	19
After 20 min	19.5	20	20	20
Stability	**BL (%)**	**CAF (%)**	**NZBC (%)**	**ALL (%)**
		Resting Parameters		
sBP	100	100	100	100
dBP	75	100	75	100
rHR	75	50	75	50
		Physical Working Capacity Test (PWC_{150})		
PWC-Power	100	100	75	75
RPE_{150}	100	75	100	100
		Time Trial (TT)		
TT-Power	100	100	100	75
HR_{mean}	100	100	100	100
HR_{max}	100	100	100	100
RER	100	75	100	100
VO_2	100	75	75	75
VCO_2	100	100	100	100
		RPE		
After 5 min	100	100	100	100
After 10 min	75	100	100	100
After 15 min	100	100	100	100
After 20 min	100	100	100	100

*ALL (caffeine + New Zealand blackcurrant phase); BL (baseline phase); CAF (caffeine phase); dBP (diastolic blood pressure); HRmax (maximum heart rate); HRmean (mean heart rate); NZBC (New Zealand blackcurrant phase); RER (respiratory exchange ratio); rHR (resting heart rate); RPE (rate of perceived exertion); sBP (systolic blood pressure); VCO_2 (carbon dioxide volume); VO_2 (oxygen volume); *significant difference to BL phase, $p < .05$.*

Table 4. Results on the contrasts from the non-parametric method Tau-U between the phases for participant A.

Variable	BL vs. CAF	BL vs. NZBC	BL vs. ALL
	(TAU-U; *p*-value)	(TAU-U; *p*-value)	(TAU-U; *p*-value)
dBP (mmHg)	0.875; .043		1.000; .021
PWC-Power (W/kg)			-0.875; .043
RPE_{150}			-0.875; .043
TT-Power (W/kg)	1.000; .021		
HR_{mean} (bpm)	1.000; .021		0.875; .043
HR_{max} (bpm)	1.000; .021		1.000; .021
VO_2 (ml)		-1.000; .021	

*ALL (caffeine + New Zealand blackcurrant phase); BL (baseline phase); CAF (caffeine phase); dBP (diastolic blood pressure); HRmax (maximum heart rate); HRmean (mean heart rate); NZBC (New Zealand blackcurrant phase); PWC (physical working capacity); RPE (rate of perceived exertion); TT (time trial); VO_2 (oxygen volume); *significant difference to BL phase, $p < .05$.*

Table 5. The median results of the resting values, the physical working capacity test, and the time trial for participant B.

Level	BL	CAF	NZBC	ALL
		Resting Parameters		
sBP (mmHg)	120	129	121	130*
dBP (mmHg)	72	74	73	75*
rHR (bpm)	48	43	49	44
		Physical Working Capacity Test (PWC_{150})		
PWC-Power (W/kg)	3.36	3.26	3.25	3.26
RPE_{150}	19	17.5	18	18
		Time Trial (TT)		
TT-Power (W/kg)	2.76	2.94*	3.13*	3.29*
HR_{mean} (bpm)	160	165*	161	165*
HR_{max} (bpm)	171	176*	172	177*
RER	0.91	0.83	0.92	0.85
VO_2 (ml)	4486	4834	4581	4791
VCO_2 (ml)	3966	4076	3949	4036
		RPE		
After 5 min	16	16	15	16
After 10 min	17.5	17.5	17	17.5
After 15 min	18.5	19	18	18.5
After 20 min	20	20	20	20
Stability	**BL (%)**	**CAF (%)**	**NZBC (%)**	**ALL (%)**
		Resting Parameters		
sBP	100	50	100	100
dBP	100	75	100	100
rHR	50	75	50	75
		Physical Working Capacity Test (PWC_{150})		
PWC-Power	75	50	50	75
RPE_{150}	100	75	75	100
		Time Trial (TT)		
TT-Power	100	100	100	100
HR_{mean}	100	100	100	100
HR_{max}	100	100	100	100
RER	100	100	75	100
VO_2	100	100	100	100
VCO_2	100	100	75	100
		RPE		
After 5 min	100	100	75	100
After 10 min	100	100	100	75
After 15 min	100	100	100	100
After 20 min	100	100	100	100

*ALL (caffeine + New Zealand blackcurrant phase); BL (baseline phase); CAF (caffeine phase); dBP (diastolic blood pressure); HRmax (maximum heart rate); HRmean (mean heart rate); NZBC (New Zealand blackcurrant phase); RER (respiratory exchange ratio); rHR (resting heart rate); RPE (rate of perceived exertion); sBP (systolic blood pressure); VCO_2 (carbon dioxide volume); VO_2 (oxygen volume); *significant difference to BL phase, $p < .05$.*

Table 6. Results on the contrasts from the non-parametric method Tau-U between the phases for participant B.

Variable	BL vs. CAF	BL vs. NZBC	BL vs. ALL
	(TAU-U; *p*-value)	(TAU-U; *p*-value)	(TAU-U; *p*-value)
dBP (mmHg)			1.000; .021
sBP (mmHg)			1.000; .021
TT-Power (W/kg)	1.000; .021	1.000; .021	1.000; .021
HR_{mean} (bpm)	1.000; .034		0.875; .043
HR_{max} (bpm)	1.000; .034		1.000; .021

*ALL (caffeine + New Zealand blackcurrant phase); BL (baseline phase); CAF (caffeine phase); dBP (diastolic blood pressure); sBP (systolic blood pressure); HRmax (maximum heart rate); HRmean (mean heart rate); NZBC (New Zealand blackcurrant phase); TT (time trial); *significant difference to BL phase, $p < .05$.*

Trends

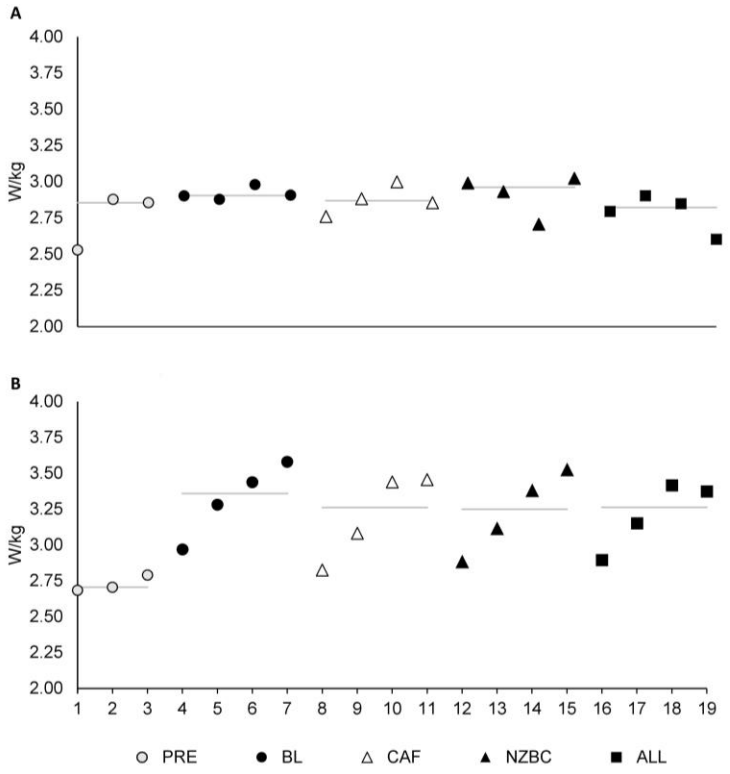
The trend analysis for the variables of participant A revealed a significant result for the rHR variable (TAU-U = -1.000; p = .042) in the CAF phase. The participant's resting heart rate decreased steadily over the four sequences.

For participant B, there were significant trends for the PWC-Power variable in the BL (TAU-U = 1.000; p = .042), CAF (TAU-U = 1.000; p = .042), and NZBC (TAU-U = 1.000; p = .042) phases. In general, there was a significant increase in PWC_{150} performance in all phases throughout the study period. Additionally, increasing trends were observed for the VCO_2 variable in the BL phase (TAU-U = 1.000; p = .042), the TT-Power variable in the NZBC phase (TAU-U = 1.000; p = .042), and the rHR variable in the ALL phase (TAU-U = 1.000; p = .042).

Levels

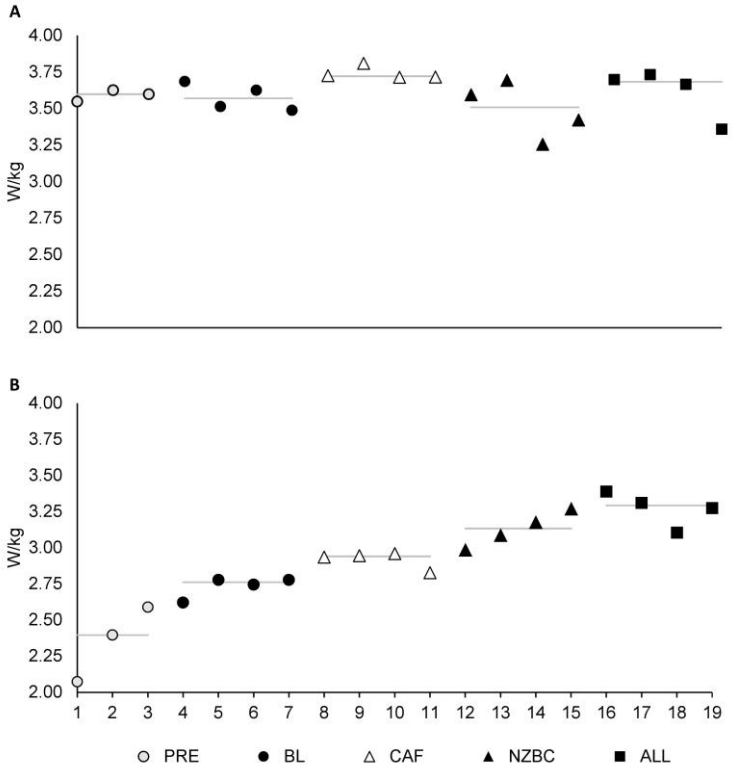
Results for each phase are shown for participant A in Table 3, Table 4, Figure 2a, and Figure 3a, and for participant B in Table 5, Table 6, Figure 2b, and Figure 3b. Only the combined results on significant contrasts from the nonparametric method Tau-U across both participants are reported below.

Most contrasts occurred between the BL and CAF phases, with significant differences observed in the RPE_{150} (TAU-U = -0.656; p = .032), TT-Power (TAU-U = 1.000; p = .011), HR_{mean} (TAU-U = 1.000; p = .002), HR_{max} (TAU-U = 1.000; p = .002), and VO_2 (TAU-U = 0.750; p = .014) variables. In addition, significant differences also occurred in the sBP (TAU-U = 0.844; p = .006), dBP (TAU-U = 1.000; p = .001), PWC-Power (TAU-U = -0.813; p = .008), RPE_{150} (TAU-U = -0.844; p = .006), TT-Power (TAU-U = 0. 688; p = .025), HR_{mean} (TAU-U = 0.875; p < .004), HR_{max} (TAU-U = 1.000; p = .001), and VO_2 (TAU-U = -0.625; p = .041) variables between the BL and ALL phases. Only the RPE_{150} value (TAU-U = -0.656; p = .032) differed between the BL and NZBC phases.



ALL (caffeine + New Zealand blackcurrant phase); BL (baseline phase); CAF (caffeine phase); NZBC (New Zealand blackcurrant phase); PRE (pre-test phase (without supplementation)); The horizontal lines show the median values for each phase.

Figure 2. The performance relative to the weight of each participant (A, B) during the PWC_{150} in the five phases.



ALL (caffeine + New Zealand blackcurrant phase); BL (baseline phase); CAF (caffeine phase); NZBC (New Zealand blackcurrant phase); PRE (pre-test phase (without supplementation)); The horizontal lines show the median values for each phase.

Figure 3. The performance relative to the weight of each participant (A, B) during the time trials in the five phases.

DISCUSSION

This explorative study tested the combined effects of caffeine and New Zealand blackcurrant supplements during maximal endurance exercise on a bike over 20 minutes. The results showed that the maximum performance of both participants developed inconsistently over the treatment phases.

During the TT, the cycling performance of participant A only increased when supplementary caffeine was taken (CAF: +3.3%; ALL: +2.2%). The performance increases were on the same levels as those reported in other studies (Doherty & Smith, 2004; Southward et al., 2018). The performance in the CAF phase was even significantly increased compared to that in the BL phase. Thus, in contrast to the results from a study by Paton et al. (2022), participant A was able to improve performance in a treatment phase compared to the BL phase. However, it should be mentioned in this comparison that in a cohort study the group means could be influenced by some non-responders. Participant A showed a lower performance in the NZBC phase. Of course, this could have been related to participant A suffering from a mild case of COVID-19. A total of four sessions were performed after participant A had recovered from COVID-19 and measurements 7, 14, 15, and 19 were affected (Table 2). In each of these four tests, participant A performed lower compared to the other tests in the phases. Due to the fact that 50% of the measurements in phase NZBC were affected by participant A's illness, the median across all data points (3.51 W/kg) probably did not reflect the actual performance of participant A (the MD of the two performances before disease: 3.65 W/kg). A study by Śliż et al. (2022) indicated that maximal heart rate and oxygen volume values could be less pronounced during cardiorespiratory graded tests, even long after COVID-19 infection. In participant A, this was found to be true with respect to oxygen volume when comparing the pre- (VO_2 = 4.67 L/min) and post-COVID-19 (VO_2 = 4.31 L/min) measurements in the NZBC phase.

Participant B exhibited an ergogenic effect of the supplements when taken individually and in combination. Compared to the BL phase, New Zealand blackcurrant (+13.4%) supplementation resulted in a greater increase in performance than caffeine (+6.5%) supplementation, while the combination of supplements (+19.2%) provided an additional ergogenic effect. Contrary to the reported results from other studies, participant B was able to significantly increase relative performance by using NZBC extract (Murphy, Cook, & Willems, 2017). The influence on the results of the reduction in body weight, which occurred due to the increased cycling since spring, and the increase in performance during the PWC_{150} over the course of the data collection period could be excluded due to the randomization of the phases because all phases were equally affected by these changes.

In the present study, the CYP1A2 genotype of the participants was not known; therefore, we could not draw any conclusions about their metabolism of caffeine. However, based on the results from studies that have examined the influence of this genotype on blood pressure in response to caffeine ingestion, slow metabolizers can show a significant increase in systolic blood pressure following caffeine ingestion (Soares, Schneider, Valle, & Schenkel, 2018) and the vasoconstriction of vessels can result in decreased blood flow to the heart and other muscles (Guest, Corey, Vescovi, & El-Sohemy, 2018). According to a review by Higgins and Babu (2013), an acute increase of 5-10% in resting systolic and diastolic blood pressure occurred after caffeine ingestion and myocardial blood flow was reduced by up to 22% during exercise. Looking at the blood pressure values of the two participants, it was noted that both participants showed increases in systolic blood pressure (participant A: 4-5%; participant B: 7-9%). Based on the results of Guest et al. (2018), it could be concluded that the performance of participant A corresponds to a slow metabolizer of genotype AC, who also achieved a performance increase of approximately 3 % with a caffeine dose of 4 g/kg. Participant B, on the other hand, showed an increase in performance consistent with genotype AA (fast metabolizer), which was not consistent with the increased blood pressure values (Guest et al., 2018).

The participants showed significant increases in their mean and maximum heart rates in the CAF and ALL phases compared to those in the BL phase (Irwin et al., 2011; Smirmaul, de Moraes, Angius, & Marcora, 2017), which could indicate stronger exertion and explain the increased performance during the TT. However, it should be mentioned that some studies have found no changes in heart rate due to caffeine, despite increased performance (Anderson, German, Harrison, Bourassa, & Taylor, 2020; Grgic, Diaz-Lara, et al., 2020). In contrast, the heart rate parameters of the participants hardly changed in the NZBC phase: participant A showed comparable values with lower power output and participant B showed significantly increased power output with similar average and maximum heart rates. The effect of New Zealand blackcurrant ingestion on heart rate has not been substantiated by other studies, so natural variations were assumed in both cases. The increase in performance could have been caused by improved blood flow to the working muscles (Cook et al., 2017), although this could not be supported by the available data.

According to a meta-analysis by Conger, Tuthill, and Millard-Stafford (2023), caffeine significantly promoted fat metabolism that was operationalized by RER (ES = 0.19). Compared to the BL phase, the RER values of both participants decreased in the CAF and ALL phases and thus, could indicate increased fat metabolism. This effect could not be measured by the RER parameter in the NZBC phase, although the anthocyanins contained in New Zealand blackcurrant extract have been shown to increase fat oxidation (Cook et al., 2015; Strauss, Willems, & Shepherd, 2018). In a study by Cook et al. (2015), the respiratory quotient did not change despite increased fat oxidation, so this variable may not adequately reflect fat oxidation.

The reduction in perceived exertion due to caffeine ingestion during TT could not be measured using the RPE parameter, although some studies have partly shown the effect of caffeine on self-perceived fatigue (Ruiz-Moreno et al., 2021). Similarly, RPE remained at the same level when NZBC was ingested. Thus, our results were similar to those from other studies that have also documented no changes in perceived exertion (Backhouse, Biddle, Bishop, & Williams, 2011; Godwin, Cook, & Willems, 2017).

Regarding data quality, for all measurements, the time sequences on the test days were standardized and implemented without changes. The participants always used their own bikes with their individually optimized settings and were able to replicate their performance under similar conditions. The chosen systematic randomized design also compensated for changes in physical conditions, so all conditions were equally affected by developmental effects. In accordance with single-case study guidelines, the present study was able to measure sufficient data points in each phase to allow for the testing of the effects of the supplements (Kratochwill et al., 2013).

Of course, the long study period of half a year caused some potential problems. The participants had to motivate themselves every week to produce their maximum performance. This was certainly difficult, especially after the periods of illness. Participant A had a cold in test weeks 12 and 14 and COVID-19 in test week 18. Participant B exhibited more severe cold symptoms in test week 15 and was physically unable to participate in the session. Consequently, the pre-established session order could not be followed for either participant. Thus, the measurements were resumed after self-assessment by the participants and the data collection phase was extended accordingly. In addition, it was not possible to check whether the capsules were taken correctly after the supplements were issued, despite regular notifications. Another limitation is the different performance level of the participants. The extent to which the level of aerobic capacity has influenced the effects of the supplements cannot be clarified based on the present studies results due to the small number of participants as well as the single-case design.

CONCLUSION

Based on this study, only the ergogenic effects of caffeine could be confirmed across both participants. Consequently, caffeine intake of 5 mg/kg body weight increased endurance performance during a time trial of 20 minutes. Only participant B indicated that both supplements could have synergistic effects. Further research in this area is needed to strengthen or weaken this indication.

AUTHOR CONTRIBUTIONS

SZ, CD and MF designed the study, with SZ and CD collecting the data. SZ conducted data analysis and interpretation, drafted the manuscript, and received critical revisions from MF and CD. All authors contributed to the article and approved the submitted version.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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