Title: Effects of New Zealand blackcurrant extract on sport climbing performance

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Abstract

Purpose Blood flow to skeletal muscles and removal of metabolic by-products during a sport climb are essential to optimise performance and recovery. New Zealand blackcurrant

(NZBC) extract enhanced blood flow and performance in other exercise modalities. We examined the effect of NZBC extract on sport climbing performance and recovery.

Methods The study employed a double-blind, randomized, cross-over design. Male sport climbers (*n*=18, age 24±6 yrs, height 179±6 cm, mass 71.4±7.8 kg, French grade 6a-8b) undertook 7 days supplementation of NZBC extract (600 mg·day^{-1} CurraNZ™ containing 210 mg anthocyanins) or a placebo (PL). Climbing ability was assessed through hang time (HT), pull-ups and total climbing time (TCT) in 3 intermittent climbing bouts on a Treadwall M6 rotating climbing wall to exhaustion with 20 min recovery between climbs. Heart rate (HR), blood lactate (BL), forearm girth (FG) and hand grip strength (HGS) were recorded.

Results NZBC extract had no effect on pull-ups but provided a trend for higher HT and significantly improved TCT (+23%) compared to PL (-11%) over 3 climbs. HR, BL, FG and HGS all indicated that 20 minutes was insufficient for physiological recovery between the 3 climbing bouts indicating accumulative fatigue regardless of condition.

Conclusion Despite indices of progressive fatigue across 3 bouts of climbing, NZBC extract facilitated not only a maintenance of TCT but an improved climbing endurance as compared with the PL condition. Blackcurrant anthocyanin-derived metabolites seems to affect physiological responses that facilitate sport climbing performance.

Keywords New Zealand blackcurrant · Sport climbing · Exercise performance · Anthocyanins · Polyphenols · Lactate

Abbreviations

BL	Blood lactate
FG	Forearm girth
HGS	Hand grip strength

HR	Heart rate
HT	Hang time
NZBC	New Zealand blackcurrant
RPE	Rating of perceived exertion
TCT	Total climbing time

Introduction

Sport climbing, comprising the three sub-disciplines lead climbing, speed climbing, and bouldering, has grown considerably over the last 30 years culminating with its inclusion in the Olympic Games in Tokyo 2020 (Lutter et al. 2017). Primarily regarded as an intermittent activity, characterised by repeated isometric contractions of the forearm muscles, sport climbing has been described as a complex and multifaceted sport with a unique set of physiological demands (Fryer et al. 2018; White and Olsen 2010).

Climbing time and distance can vary greatly between the sub-disciplines, with speed climbers completing consecutive 15m climbs as fast as possible (typically <10seconds) (Guo et al. 2019), while lead climbing requires much greater endurance capacity (lasting 2-7 minutes, ascending around 30 m) (Fanchini et al. 2013; White and Olsen 2010). Bouldering comprises a number of short technical routes, lasting approximately 30 seconds (ascending 4-5 m), with a high demand on muscular strength (Fanchini et al. 2013; White and Olsen 2010).

Initial attempts to identify key climbing performance indicators focussed on body composition and anthropometric characteristics (Watts 2004). However, the effect of local fatigue in the forearm (Soles 2008) and forearm flexor oxidative capacity index (Fryer et al. (2016) has also been indicated to be key elements for climbing performance. Muscle contraction-induced ischemia in forearm flexor muscles has been shown to result in rapid fatigue, through lack of blood flow and an accumulation of metabolic by-products including

lactate (Fryer et al. 2013, 2016; Gáspari et al. 2015; Schöffl et al. 2006). Increased lactate is associated with significant reductions in grip strength (Watts et al. 1996), while faster lactate recovery is associated with an improved climbing performance (Gajewski et al. 2009; Michailov et al. 2017). The effects of polyphenol nutritional interventions, which may enhance blood flow (Cook et al. 2017) and lactate recovery (Perkins et al. 2015), on the recovery between climbs have not yet been addressed.

Blackcurrant (Ribes nigrum) contains a high concentration of the polyphenol anthocyanin, primarily delphinidin-3-O-glucoside, delphinidin-3-O-rutinoside, cyanidin-3-O-glucoside and cyanidin-3-O-rutinoside. Blackcurrant intake has been shown to improve blood flow at rest and during exercise (Cook et al. 2017; Matsumoto et al. 2005), potentially via anthocyanin-induced vasodilation and vasorelaxation (Ziberna et al. 2013). These effects may be attributed, at least in part, to anthocyanin-induced effects on endothelial function (Speciale et al. 2014) possibly through an up-regulation of endothelial nitric oxide synthase (eNOS) and corresponding increase in endogenous nitric oxide leading to vasodilation of blood vessels in skeletal muscles (Suhr et al. 2013). In addition, reductions in oxidative stress may improve neuromuscular performance due to lower depressed activity of the sodium–potassium pump activity by reactive oxygen species (McKenna et al. 2006).

Willems et al. (2015) suggested that vasorelaxation could aid in decreasing peripheral resistance, whilst undergoing exercise, which can subsequently increase blood flow. These changes could allow for increased nutrient delivery and metabolic clearance for skeletal muscle which may contribute to enhanced exercise performance (Willems et al. 2015). This could in turn potentially support climbing performance through an improvement in blood flow to musculature of the forearms and a reduction in contraction-induced ischemia, previously identified as a limiter of performance (Fryer et al. 2013). However, it has also been demonstrated that the ability to perfuse oxygen and the muscle oxidative capacity may

be more significant than blood flow per se, as rock climbing ability increases, climbers are able to de-oxygenate both the flexor digitorum profundus and the flexor carpi radialis significantly faster and to a greater extent (Fryer et al. 2014).

NZBC extract may therefore, be able to enhance sport climbing performance through increasing blood flow sufficiently to mediate some of the ischaemia induced by prolonged isometric hold characteristic of sport climbing; consequently, optimising oxygen and substrate delivery, while maintaining removal of locally produced, fatigue-inducing metabolites including lactate, hydrogen ions, as well as heat: potentially resulting in a longer climb duration prior to failure. Alternatively, consumption of NZBC extract may result in an accelerated recovery in between climbing bouts through enhanced clearance of metabolites and a more rapid replenishment of phosphocreatine, glycogen and oxymyoglobin.

Therefore, the aim of the present study was to examine the effects of NZBC extract on physiological responses and performance of three bouts of sport climbing to volitional exhaustion, hang time and pull-ups. Our primary hypothesis was that consuming NZBC extract would enhance climbing performance, measured by duration of each climb. It was also hypothesized that NZBC extract would enhance the recovery from each bout of climbing, measured by blood lactate, handgrip strength and forearm girth.

Methods

Participants

A criterion sample of 18 male climbers with no identified health conditions and with a minimum of 3 years regular climbing experience were recruited from local climbing clubs (age 24±6 yrs, height 179±6 cm, mass 71.4±7.8 kg). Participants climbed a minimum of two times per week in both bouldering and sport climbing disciplines and were required to be at

least of the intermediate climbing group as described by Draper et al (2016) complying with a sport climbing ability of 11+ IRCRA,6a/+ (French sport grade scale), climbing group intermediate 2. Climbers were observed climbing at this grade by a climbing instructor themselves able to climb IRCRA 24 in order to verify the participants' ability. This level of ability has been used in previous climbing specific research (Brent et al. 2009) and represents the broad population of regular climbers with technical ability to complete the demands of the protocol.

The protocols were approved by the University of Chichester research ethics committee. Prior to testing, participants provided informed consent, completed a health history questionnaire and were instructed to abstain from taking any additional supplements for the duration of the study, but to otherwise maintain their usual lifestyle. Participants were advised not to undertake strenuous exercise for 48 hours before each session. Participants chose their own clothing, provided their own climbing shoes and chalk and were asked to keep all elements the same for testing sessions.

Experimental design

The study design was a double-blind crossover with an initial pre-testing and familiarisation session; therefore, study consisted of 3 sessions, all completed within 6 weeks of one another: A familiarisation session, to explain the protocol and to allow participants experience of the Treadwall rotating climbing wall (Treadwall® M6, Brewers Ledge Inc., Boston, USA) climbing speed and route, as well as the rate of perceived exertion (RPE) scale (Borg 1982). After this session, participants were randomly allocated, by flipping a coin, to either the placebo or NZBC extract, which were taken for 7 days in a double-blind, randomized, crossover design. Following the second session of climbing with performance and physiological tests, there was then a 2-week wash-out period, prior to a second 7-day supplementation and then the final session of climbing with performance and physiological

tests. Data collection was completed in a gymnasium in January. The environmental temperature for the placebo and NZBC extract condition were 11±4°C and 13±5°C, respectively.

Supplementation protocol

Prior to the two climbing trials, participants took 2 capsules each morning for 7-days; including the morning of the climb. The capsules were visually identical but contained either New Zealand blackcurrant extract (600 mg CurraNZ™, containing 210 mg anthocyanin per dose of two capsules per day; CurraNZ™, Health Currancy Ltd, Camberley, UK) or placebo (PL) (600 mg microcrystalline cellulose M102). This supplementation protocol matched that of previous NZBC extract studies (Cook et al. 2017; Strauss et al. 2018).

Pre-Climbing protocol

Testing occurred at the same time of day, same day of the week for the two supplemented climbing protocols. Participants were asked to maintain diet, hydration and exercise practices as much as possible across the testing duration, but to specifically replicate behaviours in the 48 hours prior to each testing session. Food and fluid diaries were completed during this period in order to assist with this. The participants were asked to arrive in a rested and fully hydrated state and consume a light breakfast 2-hours prior to testing. On the morning of the final day of supplementation, participants consumed their last supplement 2-hours prior to testing. A simple 5-point Likert scale was used to assess mood/willingness to participate, no changes were found between sessions. Sessions began with a light warm-up consisting of light jogging, dynamic stretching and low intensity traversing of the climbing wall.

Handgrip strength (HGS) was determined using a handgrip dynamometer (Takei 5401 Digital dynamometer, Tokyo, Japan), by slowly circumducting the arm from a vertical position while maximally contracting the fingers to achieve a grip force score. This was done alternating between sides with self-selected rest time in-between until a total of 6 measurements (3 each

side) had been taken, starting with dominant hand (primarily used for writing) (Armstrong and Oldham, 1999). Handgrip strength has been identified as controversial with regards to identifying climbing specific fatigue (Giles et al. 2019; Schweizer and Furrer 2007; Watts 2008) however, its simplicity and ability to provide instantaneous results mean it is still considered a useful test (Baláš et al. 2012). Moreover, the absence of EMG equipment and issues of practicality surrounding the use of a 90˚ or one arm hang after the maximal test, meant hand grip dynamometry was chosen to measure changes in isometric grip strength through fatigue in the context of this experiment.

After 2 minutes rest, climbers were then asked to perform their maximum number of pull-ups (PU) on; hanging from a straight arm position, in a self-paced rhythm, pulling-up until the chin was above the height of the fingerboard, the lip on the fingerboard was 30mm wide. (Entre-prises, Kelbrook UK) without kicking until volitional exhaustion.

After 2 minutes rest, participants were then asked to complete a maximal hang-time (HT) test; by maintaining a 90˚ lock-off hold in half-crimp position on a 40mm-deep campus rung. Earlobe capillary blood samples were taken 5 minutes after completion of the HT and analysed for blood lactate (YSI 2300 Stat Plus, Yellow Springs Instruments, Ohio, USA). A regression equation (Y=0.955x + 0.566) was employed to make the earlobe sample comparable with those from fingertips in climbers (Draper et al. 2006b).

Further pre-climb measures were recorded: Heart rate was recorded via a HR monitor (Polar® H7 Heart Rate Sensor, Dendermonde, Belgium). Forearm girth (FG) of both arms was taken at the mid-point between the ulnar styloid and olecranon process, marked with ink to assist with consistency between measures.

Climbing protocol

Participants completed 3 self-paced climbs on the Treadwall (Treadwall® M6, Brewers Ledge Inc., Boston, USA) continuously climbing, without stopping or resting until volitional

exhaustion on a route designed to be equivalent to a 6a French climbing grade workload. Heart rate and RPE were recorded each minute, followed by the total duration of each climb. Climbers were immediately seated after the point of failure, with RPE and forearm girth (FG) recorded. Each of the 3 climbs were followed by a 20-minute recovery protocol.

Recovery protocol

The 20-min recovery stage was separated into a passive (10-min) and active protocol (10-min) to allow for an effective rest and to mimic a previous study that demonstrated the value of active recovery for sport climbing (Draper et al. 2006a). The 10-min active recovery consisted of walking between two markers separated by a distance of 14 metres. Heart rate was recorded every minute of the recovery protocol. Post-climb handgrip strength was measured between the 6^{th} and 9^{th} recovery minutes, taking 3 measures on each side, alternating hands between each measure. FG and earlobe blood sample were taken at the 5^{th}, 10^{th} and 19^{th} minute of recovery.

Data analysis

Data were found to be normally distributed and sphericity assumed. Data are presented as mean ± SD unless stated otherwise. Statistical significance was accepted at an alpha level of 5% ($P < 0.05$) however in line with Sterne et al. (2001) results were $P < 0.10$ are discussed. Power and effect size are reported in line with Cohen (1988; 1992); with an effect size of 0.2 being considered small; 0.5 medium and 0.8 large. Contrast analysis is also presented when $P < 0.10$ (Clark-Carter 1997). All statistical procedures were conducted using statistical package SPSS v 23.0 (SPSS Inc., Chicago, IL, USA). Hang time and number of pull-ups were analysed for significant differences between the NZBC extract and placebo conditions using paired samples t-tests. The climbing performance measures of: 1) climbing duration; 2) average and peak heart rate and 3) rate of perceived exertion were analysed using repeated measures two-way ANOVAs for differences between NZBC extract and placebo conditions and between the three

consecutive bouts of climbing. Post-hoc analysis was completed using polynomial contrasts for main effects and interactions. Recovery measures of: 1) blood lactate and 3) heart rate were analysed using repeated measures three-way ANOVAs for differences between NZBC and placebo supplementation, between the three post climbing recovery periods and during recovery. Delta (Δ) values were calculated for forearm girth in order to control for body size differences by taking pre-climbing measures from each post climbing measure. Analysis for forearm girth and handgrip strength were undertaken using repeated measures two-way ANOVAs for differences between NZBC extract and placebo conditions, and post climbing recovery period. Post hoc analysis was completed using polynomial contrasts for main effects and interactions.

Results

Pre-climbing performance tests

No differences were found for the number of pull-ups to volitional exhaustion (PL: 14 ± 6; NZBC extract: 13 ± 5). Maximal hang time indicated a trend towards significance ($p = 0.062$) with a greater time in the NZBC extract (31.7 ± 11.6 sec) compared to the placebo condition (29.3 ± 10.6 sec). In the NZBC extract condition, those that were able to have a greater hang time ($n = 13$, i.e. 72%) improved by 21 ± 24%, whereas those that did not ($n = 5$, i.e. 28%) were -8 ± 7% different than in the placebo condition.

Total Climbing Time

A repeated measures ANOVA (supplementation * climb) revealed a significant interaction ($F_{(2, 34)} = 6.24$, $P = 0.005$, $\eta^2_p = 0.27$, power = 0.87) with climbing time increasing by 23% across the three climbs with NZBC and a decline of 11% with placebo (Table 1). Post hoc polynomial contrast analysis indicated that this was a linear effect and total climbing time

steadily improved for the NZBC extract condition during the three bouts whilst the same measure steadily decreased in the placebo condition (Table 1). Climbers in the NZBC extract condition managed 57 seconds longer on average in the final bout of climbing as compared to their climb in the placebo condition. No significant main effect was found for either the supplement or the climb.

Table 1. Climb duration (seconds), and heart rate (bpm) during 3 consecutive climbs.

***N* = 18 male climbers.**

		Climb duration (seconds)	HRmean (bpm)	HRpeak (bpm)
Climb 1	Placebo	455.4±199.5	164±16	174±15
Climb 2	Placebo	425.5±147.1	157±16	172±14
Climb 3	Placebo	361.1±117.6	155±17	169±18
Climb 1	NZBC extract	352.2±112.2	166±14	175±14
Climb 2	NZBC extract	414.2±265.3	158±16	171±16
Climb 3	NZBC extract	418.4±243.6	155±17	168±17

Rating of perceived exertion

No significant main effects for supplement or climb nor interaction were found for RPE although the RPEs were usually higher in the placebo condition (16.1 ± 1.4) and variance was higher in the NZBC condition (15.3 ± 2.5) (Fig. 1). However, given that the climbers worked for longer in the NZBC extract condition, this may indicate a lower perception of workload for total work done.

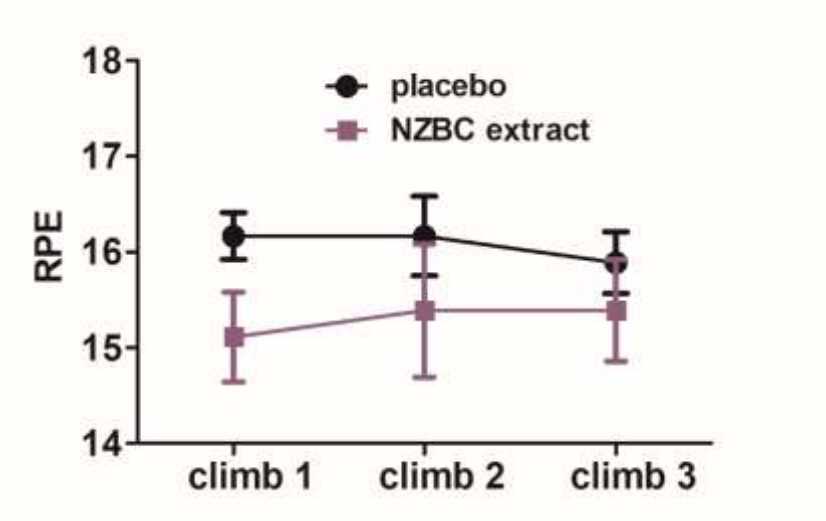

Fig. 1 RPE after each of the 3 consecutive climbs with a 20-min recovery between the climbs for placebo and NZBC extract conditions.

Heart rate during the climbs

No main effect was found for supplement nor, was there a significant interaction, indicating no differences between NZBC extract and placebo for peak heart rate during the climb (Table 1). However, peak heart rate did decrease significantly across the 3 climbs in both conditions ($F_{(2, 34)} = 8.07$, $p = 0.005$, $\eta^2_p = 0.32$, Power = 0.86).

Mean heart rate during the climb decreased across the 3 climbs in both conditions ($F_{(2, 34)} = 26.58$, $p < 0.0005$, $\eta^2_p = 0.669$, Power = 0.998) (Table 1). No main effect for supplement or interaction was found for mean heart rate. Contrast analysis showed a linear effect with peak heart rate and mean heart rate being lower in each subsequent bout of climbing, potentially indicating a decrease in work rate in each progressive climb.

Table 2. Heart rates (bpm) at four time points during the 20 min recovery between the climbs.

***N* = 18 male climbers.**

		Heart rate (bpm) during recovery			
		1 min	5 min	10 min	19 min
Climb 1	Placebo	123±16	98±12	97±15	97±13
Climb 2	Placebo	125±17	96±13	96±13	94±11
Climb 3	Placebo	119±19	95±12	92±16	92±12
Climb 1	NZBC extract	133±17	101±15	99±16	99±12
Climb 2	NZBC extract	127±21	97±15	97±16	98±13
Climb 3	NZBC extract	122±19	95±13	90±14	92±11

Heart rate during the recovery from the climbs

There were no main effects for the supplement or interactions for heart rate recovery (Table 2). However, there was a main effect for the climb/recovery bout ($F_{(2, 30)} = 15.61$, $p = 0.001$, $\eta^2_p = 0.51$, Power = 0.98). There was a linear reduction in heart rates ($p = 0.001$) during climbing so each repeated bout elicited lower heart rates, which were then consequently lower in each recovery bout (Table 2). There was also a main effect for time ($F_{(4, 60)} = 728.08$, $p < 0.0005$, $\eta^2_p = 0.98$, Power > 0.999) as heart rates decreased during recovery. This is a quadratic effect ($p < 0.0005$) so the recovery rate decelerates during the recovery period after fast initial recovery. Recovery is effectively over at 5 minutes post-climb.

Handgrip strength

Right handgrip strength demonstrated a main effect for condition ($F_{(1, 17)} = 4.98$, $p = 0.039$, $\eta^2_p = 0.23$, Power = 0.56) with mean hand grip being higher with placebo (48.1 ± 7.2 kg) than NZBC extract (45.9± 7.2 kg) (Table 3), indicating that there were no strength advantages to

consuming NZBC. No interaction was found. There was a linear reduction in the handgrip strength for each subsequent recovery bout resulting in a significant main effect on the right ($F_{3, 51} = 22.26$, $P < 0.0005$, $\eta^2_p = 0.57$, Power > 0.999) and the left-side ($F_{3, 51} = 15.61$, $P = 0.001$, $\eta^2_p = 0.51$, Power = 0.979). This indicated a progressive decline in physiological recovery of strength for each subsequent bout (Table 3).

Table 3. Handgrip strength (kg) for right (RHG) and left (LHG) hands, pre-climbing and after each climb between the 6th and 9th minute of the 20-min recovery between the climbs.

		Recovery			
		Pre-climbing	Climb 1	Climb 2	Climb 3
RHG (kg)	Placebo	53.7 ± 7.6	46.7 ± 6.8	46.6 ± 5.7	45.2 ± 7.9
	NZBC extract	52.2 ± 6.1	43.8 ± 8.6	44.0 ± 6.5	43.4 ± 7.5
LHG (kg)	Placebo	50.9 ± 8.4	42.5 ± 7.8	42.8 ± 7.9	42.0 ± 8.1
	NZBC extract	50.2 ± 8.9	42.0 ± 8.6	41.1 ± 8.1	41.1 ± 8.7

Forearm girth

Changes in forearm girth (Table 4) were analysed given that the absolute size of the arm is not physiologically significant. No main effect for supplement, nor interaction supplement * recovery bout were found. However, a weak main effect for recovery bout was found for the right-side ($F_{(2, 32)} = 2.627$, $P = 0.088$, $\eta^2_p = 0.14$, Power = 0.49) and significant in the left ($F_{(2, 32)} = 9.084$, $P = 0.001$, $\eta^2_p = 0.36$, Power = 0.962). Both are linear contrasts as forearm girth increases less after the second and third bout of climbing than the first (P<0.05) (Table 4).

Table 4. Pre-climbing forearm girth (cm) of the right (RFG) and left arm (LFG) and changes (Δ) in forearm girth (cm) immediately after the three climbs. *N* = 18 male climbers.

Parameter	Condition	Pre-climbing	Δ Post climb 1	Δ Post climb 2	Δ Post climb 3
RFG (cm)	Placebo	28.6 ± 1.4	1.17 ± 0.50	0.99 ± 0.72	0.95 ± 0.75
	NZBC extract	28.4 ± 1.5	1.10 ± 0.73	0.87 ± 0.96	0.95 ± 0.85
LFG (cm)	Placebo	28.3 ± 1.4	1.33 ± 1.10	1.03 ± 0.92	1.05 ± 1.00
	NZBC extract	28.8 ± 1.5	1.09 ± 0.65	0.75 ± 0.58	0.99 ± 0.71

Lactate

A three-way repeated measures ANOVA showed a significant main effect for Climb ($F_{2, 26}$ = 9.00, p = 0.001, η^2_p = 0.41, Power = 0.96) (Fig. 2). Contrast analysis showed this to be a linear effect (p = 0.003). Blood lactate concentration measured during recovery period followed the pattern seen by other measures taken in recovery and were reduced for each subsequent bout of climbing. This indicates climbers were able to tolerate lower levels of lactate before failure each time the climbing task was repeated. The ANOVA showed a significant difference for main effect Time ($F_{2, 26}$ = 32.55, p < 0.0001, η^2_p = 0.72, Power > 0.99). Contrast analysis revealed a linear effect (p < 0.0001). As we might expect blood lactate concentration reduced during every recovery period and this appears to be evenly distributed. The ANOVA also showed a significant interaction for Supplement * Climb ($F_{2, 26}$= 3.65, p = 0.04, η^2_p = 0.22, Power = 0.62). This was revealed as a linear contrast (p = 0.038). There were larger differences between supplements after the first bout of climbing and smaller changes after climb three. Although absolute values for lactate were higher with the NZBC extract, possibly a consequence of the longer climb duration, the main effect for supplement was not significantly different. A significant difference was also found for interaction of Climb * Time ($F_{4, 52}$ = 8.38, p < 0.0001, η^2_p = 0.39, Power = 0.998). Again,

contrast analysis showed a linear effect ($p < 0.0001$). The rate of clearance of blood lactate appears to slow after each repeat bout of climbing.

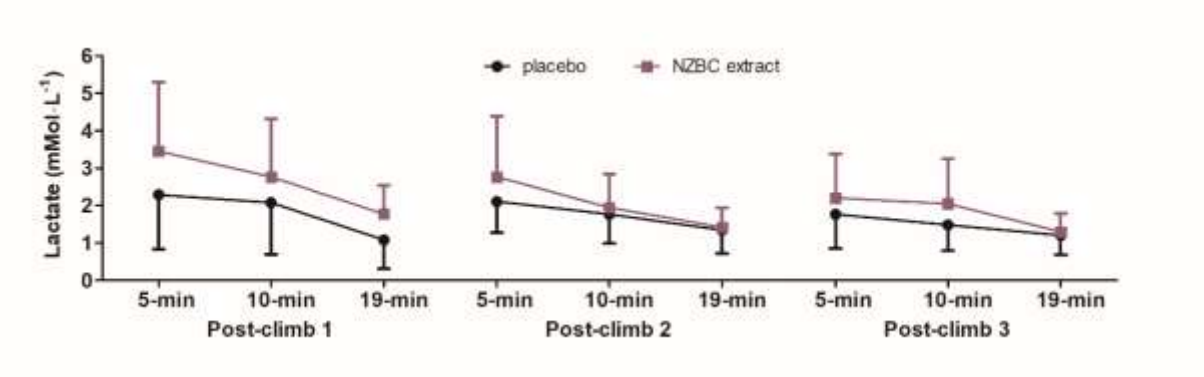

Figure 2 Blood Lactate responses after each of the 3 consecutive climbs over a 20-min recovery between the climbs for placebo and NZBC extract conditions.

Discussion

We examined the effects of New Zealand blackcurrant extract on physiological responses and performance of three bouts of sport climbing to volitional exhaustion. Our primary hypothesis was that consuming NZBC extract would enhance climbing performance; measured by duration of each climb. It was also hypothesized that recovery from each bout of climbing would be enhanced, measured by blood lactate concentration, handgrip strength and forearm girth that would be improved by intake of NZBC extract.

Findings indicate that the primary hypothesis can be supported and that the participants in this study did climb for longer, demonstrated by the significantly higher total climbing time following 7-day NZBC supplementation with a 23% improvement rather than placebo with an 11% decline in duration. There was an interaction effect given that the climbing performance declined across the three climbs following placebo supplementation and improved following NZBC extract. A trend towards an improvement in bent arm hang, an indicator of endurance in the musculature used in climbing was also observed.

NZBC extract consumption has previously been associated with improved sporting performance, in large muscle groups (e.g. Cook et al. 2015, Murphy et al. 2016, Perkins et al.

2015) but this has not been explored in a sport such as climbing which depends on the small musculature of the forearm (Fryer et al. 2016).

Previous observations of improved muscle endurance/sporting performance following consumption of NZBC have been explained with an associated increase in blood flow and potentially anthocyanin induced changes in sodium-potassium pump function. It has been established that oxygenation influences climbing performance (Fryer et al. 2018) and it is most likely that the oxygenation of the muscle is dependent upon muscle blood flow, consequently if blood flow is improved by 7-day supplementation of NZBC extract then this could explain a mechanism for the observed changes of increased climbing duration observed in this study, as accumulation of metabolites through contraction-induced ischaemia associated with fatigue in climbing would be reduced along with a potentially improved oxygenation. However, this does not explain the observed changes for the observation that performance progressively improved across the 3 climbs, demonstrating not only maintenance in performance but an improvement for each subsequent climb. Due to the incorporation of a familiarisation session, the most apparent explanation is that the climbers experienced less fatigue on each subsequent climb.

For each subsequent climb and recovery bout, there was a linear decline in heart rate which might suggest a progressively lower physiological workload which would normally be associated with muscular fatigue, resulting in a lower demand on the cardiovascular system and yet the duration of climb was longer. Similar results were seen with handgrip for which there was a progressive decline in handgrip strength for each subsequent recovery bout. Forearm girth increased progressively less in each climb, indicating a lower level of pump, a characteristic of isometric-contraction induced ischaemia in climbers where the forearm becomes swollen and painful. Results indicate no significant differences in the size of the changes in the forearm between the two supplements but results do indicate a progressively

smaller increase with each subsequent climb, again indicating a lower amount of physiological disturbance and yet achieving a longer climb time following NZBC extract. Blood lactate concentrations indicated very similar patterns to the other physiological data with no differences between supplementation condition and increases being less following each subsequent climb, suggesting that the climbers could tolerate progressively smaller amounts of lactate prior to failure. The rate of clearance seems to slow after each subsequent bout of climb, possibly due to lower heart rates, but is linear throughout recovery unlike heart rate recovery which has a quadratic pattern, being completed within approximately 5 minutes after leaving the climbing wall. The lack of difference between the supplements was supported with perceived exertion being rated the same.

The second hypothesis that recovery from each bout of climbing would be enhanced, measured by blood lactate concentration, handgrip strength and forearm girth that would be improved by intake of NZBC extract cannot be supported. These results suggest that climbers could work for longer following NZBC extract but there is no clear indicator of what the physiological mechanism behind this might be. It appears that the endurance was improved despite not having higher heart rates, perceiving a greater level of work, generating a greater concentration of lactate or working the muscles harder that may result in increased pump which would have been indicated through greater increases in forearm girth or a greater decline in handgrip. Relative to longer climb time following NZBC it is possible that the extract resulted in an improved local blood flow, resulting in a relatively lower level of pump despite no further increases in heart rate. More work is needed in order to understand the mechanisms behind performance changes during sport climbing seen with NZBC extract.

It is evident from these results that a 20 minute recovery (10 min active) recovery from a bout of climbing lasting 456 ± 198 seconds is not sufficient to maintain performance in the placebo supplement, and the progressive reduction in physiological response in each

subsequent climb potentially indicates physiological fatigue suggesting that the recovery protocol may not be sufficient however, it would not be typical for climbers to stay on the wall longer on either a training day or in competition.

The limitations of this study include that all participants were only recreational climbers. In addition, although a crossover design was used limiting issues of intra and inter participant variability, the climb was self-paced climb and climbing strategy may not have been consistent. Although there is a developing consensus that NZBC may influence blood flow and consequently oxygen and nutrient delivery (Cook et al. 2017) the mechanisms behind how it may influence performance are yet to be established; given that other systems including the brain also have enhanced blood flow by polyphenol-derived metabolites (Kennedy et al. 2019). It is possible that the effects are psychophysiological and therefore in this study is was decided not to rigorously control the workload bout but to allow the climbers to climb to volitional exhaustion. This does of course add to potential limitations of the work in that it is difficult to be mechanistic in interpreting the outcomes and further work will need to be done so that aspects of peripheral and central fatigue may be observed independently. A further limitation in interpreting the study is that it did not provide observations on the speed of the climb and the distance covered, although climbers were encouraged to take a similar approach to each climb. Climbers moved continuously throughout the protocol, although they were permitted to brief pauses to apply more chalk and shake-out, in an attempt to maintain ecological validity. While these pauses were limited, it is possible that they may have influenced muscle reoxygenation and thus performance (Baláš et al. 2016). Finally, maximal hang-time was conducted on a 40mm-deep campus rung, however a 15mm edge depth may be more representative of the average size of holds used in competitions and may have a greater relationship to climbing grade (López-Rivera and González-Badillo 2012).

Conclusions

We examined the impact of 7 days intake of New Zealand blackcurrant extract on sport climbing performance and supporting physiological indices. NZBC intake prevented the decrement in climbing performance across repeated climbs as was observed in the placebo condition and enhanced climbing duration. The data collected did not provide any apparent physiological mechanism for this as no difference was found between the NZBC extract and placebo conditions for any of the physiological indices. In fact, by the 3rd climb all physiological indices of work were lower despite a longer climb duration. Further research is required to understand the mechanisms behind these findings.

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