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Title: Effect of Intake Duration of Anthocyanin-rich New Zealand Blackcurrant Extract on Cardiovascular Responses and Femoral Artery Diameter during Sustained Submaximal Isometric Contraction

Authors: Matthew David Cook[1], Aaron Dunne[2], Michael Bosworth[2], Mark Elisabeth Theodorus Willems[2]

Affliliations: [1]University of Worcester, School of Sport and Exercise Science, Henwick Grove, Worcester, WR2 6AJ, United Kingdom, [2]University of Chichester, Institute of Sport, College Lane, Chichester, PO19 6PE, United Kingdom

Corresponding author: Prof Mark Willems, University of Chichester, Institute of Sport, College Lane, Chichester, PO19 6PE, United Kingdom. Phone: +44 (0)1243 816468, Email: m.willems@chi.ac.uk, ORCID: 0000-0003-4385-8739

ABSTRACT

Seven-day intake of anthocyanins from New Zealand blackcurrant (NZBC) extract increased cardiac output and femoral artery diameter during a sustained submaximal isometric contraction. It is not known if there are intake duration effects by NZBC extract on the isometric contraction-induced cardiovascular responses. In a repeated measures design, male participants (n=19, age: 26±4 years) performed a 120-second submaximal (30%) isometric contraction of the knee extensors at baseline and following 1, 4 and 7-days intake of 600 mg·day^{-1} NZBC extract. During the 120-second submaximal isometric contraction, femoral artery diameter and cardiovascular

responses were measured with ultrasound and beat-to-beat hemodynamic monitoring. Femoral artery was larger following 4-days (mean difference=0.046, 95% CI [0.012, 0.080 cm], p=0.005) and 7-days (mean difference=0.078, 95% CI [0.034, 0.123 cm], p<0.001) in comparison to baseline with no increase with 1-day intake. Systolic and diastolic blood pressure, heart rate and total peripheral resistance were not changed by NZBC extract at 1, 4 and 7-days intake. However, mean arterial pressure, stroke volume, cardiac output and total peripheral resistance were changed at time points during the isometric contraction following 7-days intake in comparison to 1-day intake of NZBC extract (p<0.05). Alterations in femoral artery diameter and some cardiovascular responses during a submaximal sustained isometric contraction of the knee extensors are affected by the intake duration of New Zealand blackcurrant extract, with no effects by 1-day intake. Our observations suggest that the bioavailability of blackcurrant anthocyanins and anthocyanin-derived metabolites is required for days to alter the mechanisms for isometric-contraction induced cardiovascular responses.

KEYWORDS: New Zealand blackcurrant; anthocyanins; blood flow; isometric contraction

INTRODUCTION

Blackcurrant intake has been shown to increase exercise performance (for a review see Cook et al. 2018). Alterations in blood flow (Matsumoto et al. 2005), blood vessel diameter (Cook et al. 2017a), endothelial nitric oxide synthase (Xu et al. 2004) and fatigue resistance of type I muscle fibers (Willems et al. 2020) are possible mechanisms. These alterations are likely in response to the antioxidant and anti-

inflammatory properties of the blackcurrant's anthocyanins (Speciale et al. 2014), the molecules that cause the bright colours in the berry (Khoo et al. 2017). In addition, there may be a role as well for the anthocyanin-derived metabolites (Henriques et al. 2020).

Blood flow is a limiting factor of exercise performance (Bassett and Howley 2000). Therefore, nutritional interventions that alter blood flow responses are potentially beneficial to athletes. A sustained submaximal isometric contraction allows the examination of cardiovascular responses with reduced or no movement artefact. For contractions above 30% of the force of a maximal isometric contraction (i.e. 30%MVC), blood flow becomes impaired as intramuscular pressure rises above that of systolic blood pressure (Sadamoto et al. 1983). In this mode of submaximal isometric exercise, 7-days intake of New Zealand blackcurrant (NZBC) extract with 210 mg of anthocyanins has been shown to increase femoral artery diameter and cardiac output (Cook et al. 2017a) and this indicates to be a potential mechanism to improve exercise performance.

Other studies have also reported potential beneficial cardiovascular responses to blackcurrant extract intake. For example, 7-days intake of NZBC extract has been shown to increase muscle oxidative capacity by a 37% reduction in oxygen half time recovery in the flexor digitorum profundus following an occlusion of the brachial artery by pressured tourniquet in advanced and elite male rock climbers (Fryer et al, in press). Similarly, Fryer et al (2020) demonstrated in rock climbers that the time to half recovery of tissue saturation index was faster with 7-days intake of NZBC extract (NZBC: 26±17, PLA: 42±26 s) following an intermittent isometric contraction protocol at 40%MVC for 10 s with 3 s passive recovery. There was also no difference

in brachial artery flow, artery diameter or artery velocity in the three minutes of recovery.

Alterations in cardiovascular function to anthocyanin intake has shown dose responses (Rodriguez-Mateos et al. 2013; Cook et al. 2017b) with responses plateauing after intake of 310 mg of anthocyanins (Rodriguez-Mateos et al. 2013). The conversion of anthocyanins into metabolites has been linked to cardiovascular responses by increasing nitric oxide bioavailability from a reduction in nicotinamide adenine nucleotide activity (Rodriguez-Mateos et al. 2013). Furthermore, some metabolites are still present within plasma following 48-hours (de Ferrars et al. 2014), therefore it is possible that there is accumulation of metabolites and in turn, time-course responses to the intake of anthocyanins.

Montanari et al (2020) examined the effect of NZBC extract intake on cardiovascular responses following 1, 4 and 7-days of intake, for both 300 and 600 mg of NZBC extract in endurance-trained men during cycling at 65% $\dot{V}O_{2max}$. Following consumption of 600 mg, stroke volume and cardiac output decreased after day-1, was unchanged after day-4 and increased by 3.08 mL and 0.39 $L \cdot min^{-1}$, respectively, above the smallest worthwhile change after 7-days. However, this study examined cardiovascular responses during moderate intensity dynamic exercise where the intensity is higher than isometric low force contractions of single muscle groups. Furthermore, there was no consistent testing time for the participants in Montanari et al (2020), meaning that circadian variation in cardiovascular function variables could have hidden responses from intake of the NZBC extract (Cugini et al. 1993).

An examination of the duration responses to intake of NZBC extract may provide observations to inform dosing strategies. Therefore, the aim of the present study was to examine the effect of New Zealand blackcurrant extract on femoral artery diameter

and cardiovascular responses during a sustained submaximal isometric following different durations of intake. It was hypothesised that the femoral the artery diameter and cardiovascular responses would change with the duration of intake of NZBC extract, plateauing between 4 and 7-days intake.

METHODS

Participants

Nineteen men (age: 26±4 years, height: 178±6 cm, body mass: 80±6 kg) provided written informed consent to participate in the study. Participants were not current smokers or habitual users of antioxidant supplements (including vitamins C and E and anthocyanin products). The study was approved by the University of Chichester Research Ethics Committee (approval code: 1617_30) with protocols and procedures performed in accordance with the ethical principles outlined by the Declaration of Helsinki (World Medical Association, 2013).

Experimental Design

The study was a repeated measures design, with participants visiting the laboratory for five visits at the same time of day (8:00-10:00 am) (see Figure 1 for the timeline of experimental sessions and measurements). Visit one allowed for height (Harpenden Wall Mounted Stadiometer, UK) and body mass (Kern ITB, Kern, Germany) measurements and for familiarisation of the study procedures and protocols. Visit two was used as the baseline measures, with visits three, four and five following 1, 4 and 7-days intake of New Zealand blackcurrant intake (CurraNZ®, Health Currancy Ltd., Surrey, UK). Participants consumed 600 mg·day^{-1} of NZBC extract from two 300 mg NZBC extract capsules. Each NZBC extract capsule contained 105 mg of

anthocyanins, consisting of 35–50% delphinidin-3-rutinoside, 5–20% delphinidin-3-glucoside, 30–45% cyanidin-3-rutinoside, and 3–10% cyanidin-3-glucoside. Participants consumed both NZBC capsules every morning for the 7-days of intake. On the testing days (i.e. day 1, 4 and 7) participants consumed both capsules two hours before arrival at the laboratory. For all testing days (i.e. baseline, day 1, 4 and 7), participants were also instructed to standardise their breakfast with one slice of unbuttered toast and water. The participants were instructed to not consume alcohol in the 24-hours before the testing sessions and be well rested.

In the first familiarization visit, participants were positioned with individual settings on a testing bench so that hip and knee angles were 90˚ and these settings were replicated for the subsequent experimental visits. Participants femoral artery was then isonated by ultrasound in the transverse plane approximately 7 cm below the inguinal ligament and then the location marked by pen (MicroMaxx Doppler ultrasound, Sonosite, Inc; Bothwell, WA, USA). This was followed by participants completing warmup submaximal isometric contractions (~50%MVC held for 5 s) with a few minutes rest between contractions. Participants then completed three maximal isometric voluntary contractions (MVC) with 2-minutes rest between contractions. The highest force over a time period of 0.5 s was determined, and a line was placed on the computer screen displaying the 30% of the MVC force. Subsequently, participants completed the 120-second 30%MVC for all experimental sessions. During the 120-second submaximal sustained isometric contraction, whole body cardiovascular measurements were recorded using a beat-to-beat pressure monitoring system (Finapres®, Finapres Medical Systems BV, Amsterdam, The Netherlands) and diameter of the femoral artery measured by ultrasound.

Testing of Isometric Contractions

On the testing bench, participants were attached with straps across the shoulder and hip, and the participants dominant ankle was attached to a s-beam load cell (RS 250 kg, Tedea Huntleigh Cardiff, UK) with a steel chain and metal cuff with a soft strap cuff positioned proximal to the fibrular notch and medial malleolus. Participants completed three maximal voluntary isometric contractions of the knee extensors with standardised instructions (Gandevia 2001) with the isometric muscle force recorded with a sampling frequency of 1000 Hz using Chart 4 V4 1.2 (AD Instruments, Oxford, UK).

Ultrasound of Femoral Artery

The femoral artery during the sustained 120-seconds isometric contraction at 30%MVC was captured using ultrasound (MicroMaxx portable ultrasound, Sonosite, Bothell, WA, USA) with an 8-MHz linear transducer in B-mode and approach angle of 90º. Three ultrasound images were captured during diastole at ~30, 60, 90 and 120 seconds of the submaximal isometric contraction (method adapted from Shoemaker et al. 1997). Images were taken while the participants hip angle was at 90º, therefore the artery was insonated 7 cm below the inguinal ligament to avoid the femoral artery bifurcation.

Measurements of cardiovascular responses

Beat-to-beat, non-invasive cardiovascular responses were recorded using the Finapres®. In short, a cuff was placed around the finger between the distal interphalangeal joint and proximal interphalangeal joint of the left hand and was inflated to measure the waveform of a cardiac cycle. During the sustained

submaximal isometric contraction with simultaneous recording of cardiovascular responses, participants were instructed to keep their hand stationary on their lap to avoid movement artifacts. Recordings during the sustained submaximal isometric contraction were averaged around 6 consecutive beats around each time point that was analysed (i.e. 15, 30, 45, 60, 90, 105 and 120 s). Cardiovascular parameters that were measured were systolic and diastolic blood pressure, mean arterial pressure, stroke volume, cardiac output, heart rate and total peripheral resistance (Beatscope 1.1a., Finapres Medical Systems BV, Amsterdam, The Netherlands).

Statistical Analysis

Statistical analysis was conducted using SPSS 26.0 (SPSS, IBM SPSS Statistics Armonk, NY: IBM Corp). Data normality was assessed using Kolmogorov-Smirnov test. A one-way repeated measures ANOVA was used to compare the average isometric force during the 120-second submaximal isometric contraction. Differences between the cardiovascular function variables was analysed by a condition (baseline and 1, 4 and 7-day intake) by time-point (15, 30, 45, 60, 75, 90, 105, and 120 s) repeated measures ANOVA with Bonferroni *post hoc* comparison. Differences in the femoral artery diameter were analysed by a condition (baseline, 1, 4 and 7-day intake) by time-point (30, 60, 90, and 120 s) repeated measures ANOVA with partial-eta^2 (ηp^2) reported and Bonferroni *post hoc* comparison undertaken. The effect sizes for partial-eta^2 were determined as small, medium, and large when values were 0.01-0.06, 0.06-0.14 and ≥0.14, respectively (Lakens 2013). Homogeneity of data was assessed using Mauchley's Test of Sphericity and when violated, Greenhouse-Geiser adjustments were made. Data are presented as means±SD with significance accepted at $p<0.05$. Furthermore, to aid interpretation, mean difference (MD) and 95%

confidence intervals (CI) were determined. Where responses were found significant, Cohen's *d* effect sizes were calculated (Cohen 1998) with an effect size of <0.2 reported as trivial, 0.2-0.49 as small, 0.5-0.69 as moderate and ≥0.8 as large. Due to poor acquisition of a wave form from the Finapres® in two participants, data of 17 participants were analysed. From the ~7% change in femoral artery following 600 mg·day^{-1} of NZBC extract in Cook et al (2017a), an α-priori power analysis indicated a sample size of 19 would allow a detection of a 7% increase in femoral artery diameter with a high statistical power (1−β = 0.95: 0.05 = α level).

RESULTS

Isometric force

In visit one, participants achieved an isometric MVC force of 666±145 N. As expected, there were no differences between the intake durations ($F_{(2.117, 38.099)}$=1.909, p=0.160, ηp^2=0.096) for the average isometric force during the 120-second submaximal contraction (~30%MVC) for subsequent testing days (baseline: 201±43, Day 1: 205±40, Day 4: 203±38, Day 7: 203±40 N).

Femoral Artery Diameter

The femoral artery diameter did not demonstrate a time effect ($F_{(1.759, 31.668)}$=0.656, p=0.507, ηp^2=0.035) or interaction effect ($F_{(4.417, 79.509)}$=0.601, p=0.679, ηp^2=0.032) during the submaximal sustained isometric contraction. However, there was a condition effect ($F_{(3,54)}$=11.798, p<0.001, ηp^2=0.396) for the femoral artery diameter. In comparison to baseline, the femoral artery diameter was larger following 4-days (p=0.005, MD=0.046, 95% CI [0.012, 0.080 cm]) and 7-days intake of NZBC extract (p<0.001, MD=0.078, 95% CI [0.034, 0.123 cm]). In addition, the femoral artery

diameter was also larger following 7-days of intake compared to 1-day of intake of NZBC extract (p=0.001, MD=0.064, 95% CI [0.023, 0.104 cm]). There were also differences for the femoral artery diameter between the intake duration conditions at time points during the 120-seconds submaximal sustained isometric contraction (Table 1). At 60-seconds during the isometric contraction, the femoral artery diameter was larger in the 7-days intake condition compared to baseline (p=0.011, d=0.529, MD=0.064, 95% CI [0.012, 0.116 cm]) and 1-day of intake (p=0.016, d=0.429, MD=0.054, 95% CI [0.08, 0.100 cm]). At 90-seconds of the isometric contraction, the femoral artery diameter was larger following 4-days (p=0.007, d=0.540, MD=0.067, 95% CI [0.015, 0.118 cm]) and 7-days intake of NZBC extract in comparison to baseline (p=0.001, d=0.791, MD=0.091, 95% CI [0.032, 0.150 cm]). In addition, following 7-days intake of NZBC extract, the femoral artery diameter was larger than 1-day of intake (p=0.004, d=0.517, MD=0.066, 95% CI [0.018, 0.113 cm]). At 120-seconds of the submaximal isometric contraction, the femoral artery diameter following 7-days intake of NZBC extract was larger than baseline (p=0.030, d=0.874 MD=0.102, 95% CI [0.007, 0.197 cm]) and 1-day intake (p=0.046, d=0.497, MD=0.071, 95% CI [0.001, 0.142 cm]).

Cardiovascular Responses

For systolic blood pressure, there was an effect of time ($F_{(2.389, 38.22)}$=60.328, p<0.001, ηp^2=0.790) with no condition ($F_{(3, 48)}$=1.047, p=0.380, ηp^2=0.061) or interaction effect ($F_{(24, 384)}$=1.124, p=0.313, ηp^2=0.066) (Figure 2A). Similarly, for diastolic blood pressure, there was an effect of time ($F_{(2.501, 41.273)}$=80.498, p<0.001, ηp^2=0.834) with no condition ($F_{(3, 38.046)}$=1.744, p=0.171, ηp^2=0.098) or an interaction effect ($F_{(24,384)}$=1.386, p= 0.108, ηp^2=0.080) (Figure 2B). For mean arterial pressure, there

was an effect of time ($F_{(2.937, 46.990)}$=82.117, p<0.001, ηp^2=0.838), with a condition effect ($F_{(3, 2.476)}$=2.826, p=0.048, ηp^2=0.150) and an interaction effect ($F_{(24, 384)}$=1.586, p=0.041, ηp^2=0.090) (Figure 2C). Post hoc testing indicated that at 120 seconds during the submaximal sustained isometric contraction, 1-day was different to 4-days (p=0.028, d=-0.816, MD=-14.824, 95% CI [-28.384, -1.263 mmHg]) and 7-days intake of NZBC extract (p=0.019, d=-0.788, MD=-12.059, 95% CI [-22.536, -1.582 mmHg]) (Figure 2C). For heart rate, there was an effect of time ($F_{(2.317, 37.065)}$=37.251, p<0.001, ηp^2=0.700) with a trend for differences between the conditions ($F_{(3, 48)}$=2.452, p=0.075, ηp^2=0.133), however, there was no interaction effect ($F_{(24, 384)}$=0.742, p=0.808, ηp^2=0.044) (Figure 2D). For stroke volume, there was an effect of time ($F_{(3.125, 49.996)}$=3.462, p=0.022, ηp^2=0.178) with a trend for a condition ($F_{(1.533, 24.853)}$=3.094, p=0.074, ηp^2=0.162) and interaction effect ($F_{(24, 384)}$=1.429, p=0.089, ηp^2=0.082). At 15 seconds during the contraction, 1-day was different to 7-days intake (p=0.027, d=0.740, MD=9.124, 95% CI [0.802, 17.445 mL]). At 75-seconds of the contraction 7-days intake of NZBC extract, stroke volume was larger than baseline (p=0.027, d=0.659, MD 12.094, 95% CI [1.057, 23.131 mL]), 1-day intake (p=0.009, d=0.730, MD=11.341, 95% CI [2.362, 20.321 mL]) and 4-days intake (p=0.035, d=0.874, MD=13.671, 95% CI [0.753, 26.588 mL]). At 105 seconds of the contraction 7-days intake was different to 1-day intake (p=0.021, d=0.680, MD=8.294, 95% CI [1.018, 15.570 mL]) (Figure 2E). For cardiac output, there was an effect of time ($F_{(3.646, 58.336)}$=14.623, p<0.001, ηp^2=0.478) with a condition effect ($F_{(1.959, 31.351)}$=4.926, p=0.014, ηp^2=0.235) and no interaction effect ($F_{(24,384)}$=1.316, p=0.148, ηp^2=0.076). At 15-seconds of the contraction, cardiac output was higher following 7-days intake in comparison to 1-day (p=0.050, d=0.705, MD=0.689, 95%CI [0.01, 1.377 $L \cdot min^{-1}$]) and 4-days intake p=0.002, d=0.298, MD=0.884,

95%CI [0.296, 1.472 L·min^{-1}]). Cardiac output was also higher following 7-days intake in comparison to 1-day at 75-seconds (p=0.036, d=0.651, MD=1.207, 95%CI [0.051, 2.003 L·min^{-1}]), 90-seconds (p=0.048, d=0.302, MD=0.968, 95%CI [0.006, 1.929 L·min^{-1}]) and 120-seconds (p=0.004, d=0.287, MD=1.379, 95%CI [0.034, 2.723 L·min^{-1}]) of the submaximal sustained isometric contraction. At 120-seconds of the submaximal sustained isometric contraction, cardiac output was also larger following 1-day in comparison to baseline (p=0.004, d=0.695, MD=0.956, 95%CI [0.275, 1.638 L·min^{-1}]) (Figure 2F). For total peripheral resistance, there was an effect of time ($F_{(3.391, 54.250)}$=15.179, P<0.001 ηp^2=0.487) with no condition ($F_{(3,48)}$=0.8000, p=0.500, ηp^2=0.048) or interaction effect ($F_{(24, 384)}$=1.113, p=0.326, ηp^2=0.065) (Figure 2G).

DISCUSSION

The present study demonstrated that changes in femoral artery diameter by intake of NZBC extract during a sustained submaximal isometric contraction of the knee extensors follow intake duration responses. In comparison to baseline, the femoral artery diameter was higher following 4 and 7-days intake. Furthermore, 7-days intake of NZBC extract also provided a higher femoral artery diameter than 1-day of intake. Moreover, variables of cardiovascular function such as mean arterial pressure, stroke volume and cardiac output also demonstrated similar responses.

The results of the present study are comparable to the findings of Cook et al (2017a). In Cook et al (2017a), changes in femoral artery diameter and cardiovascular responses were also demonstrated during a 30%MVC of the knee extensors following 7-days intake of NZBC extract. The study by Cook et al (2017a) demonstrated moderate to large effects in femoral artery diameter increases (i.e. d=0.52-0.82) and

the present study is directly comparable demonstrating similar effects following 7-days intake (i.e. *d*=0.53-0.87). The findings of the present study also compare to the observations by Montanari et al (2020) where intake duration responses demonstrated changes in stroke volume, cardiac output and total peripheral resistance following intake of 600 mg NZBC extract for 7-days but not after 1-day. The findings of the present study demonstrated that the intake duration response changes occur in healthy untrained but physically active men. The study by Cook et al (2017a) used the same methods as the current study, with a different study design, but the participants were also healthy, untrained physically active men. Furthermore, Cook et al (2017b) used trained cyclists and demonstrated altered cardiovascular responses at rest following 7-days NZBC extract intake. Therefore, the current findings demonstrated that duration responses occur following intake and inform dosing strategies. However, future research should address if these responses occur in participants with different levels of training or disease.

The results of the present study contribute to the understanding of dosing strategies of NZBC extract and are potentially explained by a build-up of anthocyanin-derived metabolites affecting the mechanisms that cause responses. For example, Czank et al (2013) observed metabolites from the anthocyanin cyanidin-3-glucoside to remain within plasma 48-hours following intake. It is therefore possible that the regular intake for a minimum of 4-days allows for build-up that results in these responses. The present study also demonstrated that femoral artery diameter changes on day 4 and 7 are not acute responses to the intake of capsules 2-hours before arrival at the laboratory. If acute responses were present, then changes following 1-day of intake would have been expected, and that was not the case.

The mechanisms that could explain the results of the present study stem from the known effects of berry polyphenols on increasing nitric oxide bioavailability and in turn, regulating blood hemodynamics. For example, Nakamura et al (2002) demonstrated that blackcurrant concentrate to cause vasorelaxation in a dose dependent manner in rat thoracic aorta *ex vivo* through mechanisms that upregulate nitric oxide synthesis. Furthermore, anthocyanidins (i.e. the aglycone form of anthocyanins) have also been demonstrated to reduce endothelial-derived endothelin-1 expression, a vasoconstrictor, in human umbilical vein endothelial cells while also increasing eNOS by up to 78% *in vitro* (Lazzè et al. 2006).

The results of the present study also support other findings from this research group as previous studies have used primarily a 7-day dosing period (e.g. Cook et al. 2017ab). Responses to an intake longer than 7-days are less clear, and therefore warrant future research. One study demonstrated higher exercise-induced fat oxidation with 14 days compared to 7 days intake of NZBC extract (Sahin et al. in press). Previous studies with 7-day intake have demonstrated exercise performance increases in cycling (Cook et al. 2015), high-intensity treadmill running (Perkins et al. 2015) and sports climbing (Potter et al. 2020). However, these studies did not measure hemodynamic responses. Muscle performance is a determinate of blood flow (Murthy et al. 2001), accumulation of lactate and acidosis (Bonitch-Góngora et al 2012). Therefore, the results from the present study support that the mechanisms that modulate blood flow from NZBC intake may cause these performance increases.

Exercise results in the production of reactive oxygen species and inflammation. Both are known to contribute to the control of peripheral vascular resistance, and in turn skeletal muscle blood flow (Trinity et al. 2016). Furthermore, blood flow is linked to tissue perfusion and interventions that improve blood flow may increase tissue

oxygen utilisation (Mortensen et al. 2008). Anthocyanins, such as those within blackcurrant, are known to have anti-inflammatory and antioxidant properties (Speciale et al 2014). Therefore, the intake of NZBC extract in the present study may be linked with these properties to explain the increased femoral artery diameter and increased cardiac output during the isometric exercise.

Limitations

A limitation of the present study was that participants did not undertake the experiment after consuming a placebo (i.e. no blinding or cross-over). However, it is worth noting that Cook et al (2017a) used similar methods of measurements to the present study and observed similar results for the changes in femoral artery diameter when using a placebo with 7-day intake. The present study only assessed cardiovascular responses during isometric exercise at 30% MVC for 120-seconds. Previous studies demonstrating performance effects have used whole-body exercise (Cook et al. 2015; Perkins et al. 2015; Potter et al. 2020) and as a result, the practical application of the present study may be limited. Therefore, future studies should examine cardiovascular responses during exhaustive whole-body exercise to determine if the cardiovascular changes occur in this type of exercise.

Conclusions

Femoral artery diameter, mean arterial pressure, stroke volume, cardiac output and total peripheral resistance during a 30% maximal voluntary contraction of the knee extensors are changed following different durations of intake of 600 mg New Zealand blackcurrant extract in young healthy men. There were no changes following 1-day of intake, but changes were observed following 4 and 7-days intake. Therefore,

cardiovascular function and femoral artery diameter during isometric exercise demonstrate different responses following different durations of intake. It seems that the bioavailability of blackcurrant anthocyanins and anthocyanin-derived metabolites is required for days to alter the mechanisms for isometric-contraction induced cardiovascular responses.

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Conflict of interest

The authors declare no conflict of interest.

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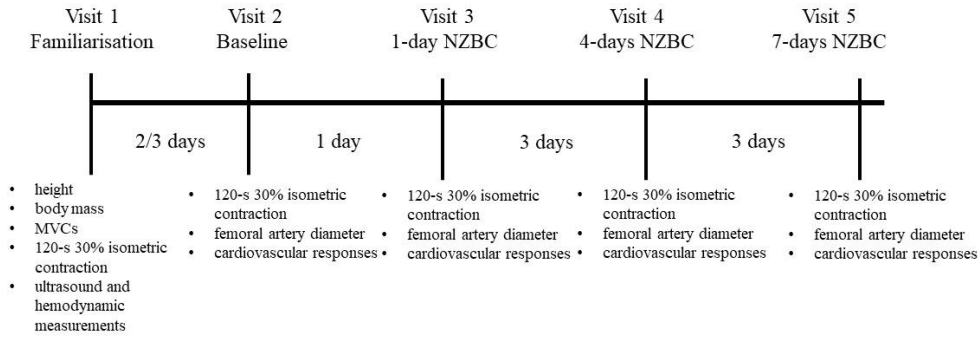

Figure 1 – Experimental design and measurements during the five visits. MVC, Maximal Voluntary Contraction; NZBC, New Zealand blackcurrant.

Figure 2 – (A) Systolic Blood Pressure, (**B**) Diastolic Blood Pressure, (**C**) Mean Arterial Pressure, (**D**) Heart Rate, (**E**) Stroke Volume, (**F**) Cardiac Output (**H**) Total Peripheral Resistance during a 120-s 30% MVC of the knee extensors at baseline and following 1, 4 and 7-days intake of New Zealand blackcurrant (NZBC) extract capsules. Data are mean±SD. [a] 1-day different to baseline, [b] 4-day different to baseline, [c] 7-day different to baseline, [d] 4-days different to 1-day, [e] 7-days different to 1-day, [f] 7-days different to 4-days.