

1 Acute consumption of varied doses of cocoa flavanols does not improve muscle recovery  
2 following exercise-induced muscle damage in active males and females

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22 Abstract

23 Polyphenol consumption has become a popular method of trying to temper muscle damage.  
24 Cocoa flavanols (CF) have attracted attention due to their high polyphenol content and  
25 palatability. As such, this study will investigate whether an acute dose of CF can aid recovery  
26 following exercise induced muscle damage (EIMD). The study was a laboratory-based,  
27 randomised, single-blind, nutrient-controlled trial involving 23 participants (13 females, 10  
28 males). Participants were randomised into either control ~0mg CF (CON, n=8, 4 females), high  
29 dose of 830mg CF (CF<sub>830</sub>, n=8, 5 females) or supra dose of 1245mg CF (CF<sub>1245</sub>, n=7, 4  
30 females). The EIMD protocol consisted of five sets of 10 maximal concentric/eccentric  
31 hamstring curls and immediately consumed their assigned drink following completion. To  
32 measure muscle recovery, maximal voluntary isometric contraction (MVIC) of the knee flexors  
33 at 60° and 30°, a visual analogue scale (VAS) and lower extremity function scale (LEFS) were  
34 taken at baseline, immediately, 24, 48 and 72-hr post-EIMD. There was a main effect for time  
35 for all variables ( $P < 0.05$ ). However, no significant differences were observed between groups  
36 for all measures ( $P \geq 0.17$ ). At 48 hr there were large effect sizes between CON and CF<sub>1245</sub> for  
37 MVIC<sub>60</sub> ( $P = 0.17$ ,  $d = 0.8$ ), MVIC<sub>30</sub> ( $P = 0.26$ ,  $d = 0.8$ ), MVIC<sub>30</sub> percentage change ( $P = 0.24$   
38  $d = 0.9$ ) and VAS ( $P = 0.25$ ,  $d = 0.9$ ). As no significant differences were observed following the  
39 consumption of CF there is reason to believe that CF offer no benefit for muscle recovery when  
40 ingested acutely.

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## 46 1. Introduction

47 Eccentric muscle contractions are typically responsible for the muscular disruption that leads  
48 to exercise induced muscle damage (EIMD) (Nikolaidis et al., 2007). Therefore, resistance  
49 training and intermittent high-intensity exercise often evoke EIMD (Owens, Twist, Copley,  
50 Howatson, & Close, 2019). Consequences of EIMD include inflammation and oxidative stress  
51 (Kanda et al., 2013), impaired force generating capacity (Twist & Eston, 2009), and increased  
52 muscle soreness (Impellizzeri et al., 2008). Optimising the time course of recovery is now a  
53 priority in modern sport, mainly due to the rapid turnaround of competitions and fixtures.  
54 Contemporary examples include tennis players performing every other day at major  
55 championships and congested fixture periods in soccer when players perform two 90 min  
56 matches within three days. Notably, injury-risk and muscular fatigue may be increased during  
57 congested fixture periods in soccer, namely due to the insufficient recovery time between  
58 matches (Ekstrand, Hägglund, & Waldén, 2011; Page, Marrin, Brogden, Greig, & Research,  
59 2019). Therefore, the aim of recovery is to restore normative values for an individual following  
60 exercise by reducing neuromuscular fatigue, soreness and restoring contractile functional  
61 capacity. To reduce fatigue and facilitate recovery, high carbohydrate protein meals or  
62 beverages, as well as high polyphenolic foodstuffs (e.g., cocoa) have become a common feature  
63 of an athlete's diet (Knapik et al., 2016). Polyphenol is an umbrella term for the different  
64 classes of plant metabolites, including flavonoids, stilbenes, phenolic acids and lignans.

65 Flavonoids are the largest group of dietary polyphenols and the most common source of  
66 antioxidants within the diet (Scalbert, Johnson, & Saltmarsh, 2005). In recent years, a subclass  
67 of flavonoids, known as flavanols, such as catechin and epicatechin, have attracted much  
68 attention as health promoting nutrients. Sources of flavanols include lychees, apples, teas,  
69 broad beans and cocoa (Williamson, 2017). Cocoa has the highest proportion of flavanols per  
70 serving than any other natural source (Lee, Kim, Lee, & Lee, 2003). Previous research has

71 focused on the effects of cocoa flavanols (CF) on the cardiovascular system, with evidence  
72 suggesting CF intake can reduce endothelial dysfunction by improving flow mediated dilation  
73 (Hooper et al., 2012) and reducing blood pressure (Buitrago-Lopez et al., 2011). Furthermore,  
74 CF have been shown to enhance endogenous antioxidant capacity (Serafini & Peluso, 2016),  
75 limit oxidative stress (Allgrove et al., 2011), and influence the inflammatory process by  
76 reducing both platelet aggregation and the stimulation of neutrophils (Ellinger & Stehle, 2016).

77 Regarding muscle recovery and exercise, research has shown that acute (single dose on day of  
78 exercise stimulus) and sub-chronic (regular intake for  $\geq 14$  days) CF supplementation of  $\geq 200$   
79 mg reduces exercise-induced oxidative stress (Allgrove et al., 2011; Davison, Callister,  
80 Williamson, Cooper, & Gleeson, 2012). Furthermore, in relation to exercise, the ingestion of  
81 CF may improve sprint performance by potentially preventing ROS-increased calcium  
82 sensitivity of myofilaments within working muscles, therefore, delaying fatigue (de Carvalho  
83 et al., 2019; Patel, Brouner, & Spendiff, 2015). However, evidence is lacking regarding the  
84 impact of CF on markers of muscle recovery, such as perturbations in muscle function and an  
85 increase of perceived soreness. One such study used a CF dose too low (74 mg CF and 8 mg  
86 epicatechin) to be effective (Morgan, Wollman, Jackman, & Bowtell, 2018). Benefits begin to  
87 be observed at doses of  $\sim 700$  mg CF; and more importantly, with  $> 50$  mg epicatechin, the most  
88 biologically active flavanol (Schroeter et al., 2006). However, an optimal dose is not yet known  
89 in addition to any potential dose response. Furthermore, previous research that investigated the  
90 impact of CF on muscle recovery did not induce notable muscle damage using a drop jumps  
91 protocol (de Carvalho et al., 2019) and a downhill running protocol (Peschek, Pritchett,  
92 Bergman, & Pritchett, 2013). This can be defined as reductions in muscle force-generating  
93 capability of  $\geq 20\%$  following EIMD (Paulsen, Ramer Mikkelsen, Raastad, & Peake, 2012).  
94 Therefore, making conclusions about the impact of CF on markers of muscle damage is  
95 difficult, indicating that more research is warranted. Furthermore, none of the previous studies

96 involved female participants, likely due to the purported protective effects of oestrogen against  
97 muscle damage (Tiidus, 2003) and physiological variations across the menstrual cycle  
98 (Hayashida, Shimura, Sugama, Kanda, & Suzuki, 2016). Therefore, investigating the effect of  
99 CF supplementation on muscle recovery in females is required.

100 Therefore, the aims of this study were twofold; *i*) to investigate the impact of an acute dose of  
101 CF on indices of muscle recovery *ii*) to compare two different doses of CF on indices of muscle  
102 recovery. The hypothesis for this study was that EIMD might be attenuated following acute  
103 consumption of CF, with the highest dose offering the most benefit.

## 104 2. Methods

### 105 2.1 Participants

106 Following institutional ethical approval and in agreement with the Declaration of Helsinki, 30  
107 participants consented to take part between the months of April 2019 to October 2019;  
108 however, only 23 completed the study (13 females, 10 males) due to the following reasons;  
109 two due to injury and five due to unforeseen circumstances following baseline testing. An *a*  
110 *priori* power calculation determined that a sample size of 21 was required for 80% power and  
111 to detect significance, based on the effect size from previous research regarding MVIC  
112 recovery at 48 hr (Bowtell, Sumners, Dyer, Fox, & Mileva, 2011). Baseline testing involved  
113 maximal voluntary isometric contractions (MVIC) of the knee flexors to assess muscle function  
114 and measures of perceived muscle soreness using a visual analogue scale (VAS) and lower  
115 extremity function scale (LEFS). All participants were classed as recreationally active and  
116 injury free for the previous six-months (both informed *via* self-report) and were not taking any  
117 dietary supplements (e.g., vitamin C, glutamine, or branched-chain amino acids). Participants  
118 were asked to avoid anti-inflammatory medications and resistance training during  
119 participation. A menstrual cycle questionnaire (Brown, 2017) was completed by the female

120 participants involved to reliably estimate cycle phase. The luteal phase was selected for testing  
121 or an equivalent period for participants who were on hormonal contraception, as to avoid peak  
122 oestrogen concentrations observed during the follicular phase (Brown, 2017). Participants  
123 completed each day within  $26\pm 2$  hr of original participation to account for diurnal influence.

## 124 2.2 Study Design

125 The study was a laboratory-based, randomised, single-blind, nutrient-controlled trial.  
126 Participants were randomised into a control (CON), high (CF<sub>830</sub>) or supra (CF<sub>1245</sub>) group and  
127 remained unaware of their allocation for the entirety of the study. Participants were required to  
128 come to the laboratory for five days, the first being baseline testing and familiarisation of the  
129 EIMD protocol (ten sub-maximal concentric-eccentric hamstring curls). The remaining four  
130 days took place consecutively; as such, measures were taken in the following order: baseline,  
131 immediately post-EIMD (0 hr), 24, 48 and 72 hr post-EIMD. For randomisation, participants  
132 were assigned to separate strata, 'strong' and 'not strong', based on their baseline MVIC values  
133 and randomised into matched and counterbalanced groups (using random.org). To decide what  
134 could be classified as strong or not, a normative MVIC strength index was used [Risberg et al.  
135 (2018) for females and Ruas, Minozzo, Pinto, Brown, and Pinto (2015) for males]. Following  
136 this, eight participants were allocated to the control group (four females, four males), eight to  
137 the CF<sub>830</sub> group (five females, three males), and seven to the CF<sub>1245</sub> group (four females, three  
138 males).

139 \*\*\*INSERT TABLE 1 NEAR HERE\*\*\*

## 140 2.3 Muscle Function

141 Values were recorded for knee flexor MVIC using the isokinetic dynamometer (Cybex  
142 NORM®, Model 770, CA, USA), providing a reliable quantification of decrements in muscle  
143 function for assessing EIMD (Warren, Lowe, & Armstrong, 1999). Knee angles of 60°

144 (MVIC60) and 30° (MVIC30) of the anatomical zero (full knee flexion) were selected due to  
145 the differences in muscle activation at various knee angles; biceps femoris has increased  
146 activation at reduced angles, whilst semitendinosus and semimembranosus at greater knee  
147 angles (Onishi et al., 2002).

#### 148 2.4 Subjective Soreness

149 Soreness was recorded using a 200 mm VAS, which has been previously included as a  
150 validated measure of subjective soreness (Peschek, Pritchett, Bergman, & Pritchett, 2013). The  
151 LEFS is a validated questionnaire which quantifies an individuals perceived level of muscle  
152 function using 20 hypothetical activities that are scored from 0 to 4; 0 = extreme difficulty; 4  
153 = no difficulty (de Carvalho et al., 2019).

#### 154 2.5 Muscle Damaging Protocol

155 The exercise protocol used to induce muscle damage was adapted from White et al. (2008)  
156 using the Cybex Norm Isokinetic Dynamometer (CSMi, Boston, Massachusetts). Participants  
157 were then secured into the dynamometer at 85° hip flexion using straps to isolate the knee and  
158 remove hip flexor involvement. Body position was noted during baseline testing and replicated  
159 throughout. A specific warm-up consisting of 10 concentric/eccentric contractions of the knee  
160 flexors at a self-perceived low effort level was performed pre-exercise. Following the warm-  
161 up, participants performed five sets of 10 maximal concentric/eccentric contractions of the knee  
162 flexors with an intersit rest of one minute; rotation speed was  $60^{\circ} \cdot s^{-1}$ . Participants were verbally  
163 encouraged throughout and once all repetitions were completed, the participant immediately  
164 repeated the protocol on the opposite leg.

#### 165 2.6 Nutritional Intervention

166 Participants were blinded to which group they were assigned, with only the lead researcher  
167 being aware of the contents of each drink. Participants consumed their assigned beverage  
168 within five minutes following the protocol. Each beverage consisted of 300 ml water, 60 g  
169 maltodextrin and 25 g whey protein powder (20 g protein). The cocoa powder used was a  
170 commercially available high flavanol powder (Chococru© Extraordinary Flavanol Cocoa),  
171 containing ~8.3% flavanols and a total polyphenol content of ~12% (unpublished data from  
172 Chococru©). The beverage for CF<sub>830</sub> included an additional 10 g of Chococru© cocoa powder  
173 which contained 830 mg CF (98.6 mg epicatechin) and for CF<sub>1245</sub> 15 g of Chococru© cocoa  
174 powder was added, containing 1245 mg CF (149.4 mg epicatechin; Table 2).

175 \*\*\*INSERT TABLE 2 NEAR HERE\*\*\*

## 176 2.7 Dietary Measures

177 Participants completed a 24-hour dietary recall each day of testing, totalling five food recalls,  
178 and were asked to continue eating their usual diet throughout testing. During baseline testing,  
179 participants were provided a list of high polyphenolic food and drink (cherries, blueberries,  
180 dark chocolate, green and black tea, wine, apples, lychees, pomegranates and fruit juices) to  
181 refrain from consuming three days before and during the testing period, reducing the  
182 confounding influence of other dietary polyphenols on recovery (Scalbert et al., 2005). Dietary  
183 analysis was carried out using Nutriment (Dark Green Media Ltd, ©2016).

## 184 2.8 Statistical analyses

185 Statistical analysis was performed using IBM SPSS Statistics (version 24, IBM Corp., Armonk,  
186 N.Y., USA). All data was assessed for normality, a Greenhouse-Geisser correction was used if  
187 sphericity was violated. A repeated-measures analysis of variance was used to determine  
188 interaction and time effects for the recovery variables. If any significance was observed, Fisher  
189 LSD post hoc testing was performed to identify the point of significance. Data for MVIC60



190 and MVIC30 was calculated as percentage change from baseline alongside absolute means. To  
191 calculate effect sizes, Cohen's *d* (*d*) was utilised, with the magnitude of effects considered  
192 small (0.2), moderate (0.5) and large (0.8). Significance was set at  $P \leq 0.05$  pre-analysis.  
193 Descriptive statistics are reported as means (%)  $\pm$  standard deviation (SD).

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198 \*\*\*INSERT FIGURE 1 NEAR HERE\*\*\*

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### 203 3. Results

204 There were no significant differences for participant characteristics or dietary intake between  
205 groups ( $P \geq 0.33$ ). See Table 3 for dietary intake.

206 \*\*\*INSERT TABLE 3 NEAR HERE\*\*\*

207

#### 208 3.1 Muscle function

209 Muscle function measured using MVIC at 60° and 30° found a main effect of time ( $P<0.05$ ).  
210 There were no significant differences between groups for knee flexor peak torque at MVIC60  
211 ( $P=0.99$ ) or MVIC30 ( $P=0.95$ ) at baseline. Following the exercise protocol, overall mean knee  
212 flexor peak torque reduced to 79% of baseline. There was a significant effect of time across all  
213 groups ( $P<0.05$ ). For MVIC60 there were no significant differences between groups ( $P\geq 0.17$ ).  
214 For MVIC30 there were no significant differences between groups ( $P\geq 0.55$ ).

### 215 3.2 Measures of Perceived soreness

216 Perceived soreness measured using a VAS and LEFS found a main effect of time for both  
217 measures ( $P<0.05$ ). There were no significant differences between groups for VAS scores  
218 ( $P\geq 0.39$ ). There were no significant differences between groups for LEFS scores ( $P\geq 0.75$ ).

219 \*\*\*INSERT FIGURE 2 NEAR HERE\*\*\*

220 \*\*\*INSERT TABLE 4 NEAR HERE\*\*\*

221 \*\*\*INSERT TABLE 5 NEAR HERE\*\*\*

222

## 223 4. Discussion

224 The main aim of this study was to investigate whether various doses of CF have any impact on  
225 indices of muscle recovery following EIMD. Based on the results of the current research, no  
226 significant differences were found following the addition of CF. This study corroborates  
227 previous findings that suggest an acute dose of CF has no significant impact on measures of  
228 muscle function, or measures of perceived soreness (de Carvalho et al., 2019; Morgan et al.,  
229 2018; Peschek et al., 2013).

230 Differences between this study and previous studies should be noted, in that both de Carvalho  
231 et al. (2019) and Peschek et al. (2013) used EIMD protocols that did not elicit muscle soreness

232 or deficits in muscle function in the populations they used. By contrast, the protocol used in  
233 this study elicited muscle damage as evidenced by a ~21% reduction in muscle function  
234 alongside a reduction of ~27% for perceived muscle function measured using the LEFS and a  
235 17-fold increase in perceived soreness at 48 hr post-protocol (see Tables 4 and 5), at which the  
236 negative effects of muscle damage are known to peak (Cheung, Hume, & Maxwell, 2003).  
237 Furthermore, this study targeted the hamstring muscle group as the location for inducing  
238 muscle damage when previous studies targeted the quadriceps (de Carvalho et al., 2019;  
239 Morgan et al., 2018; Peschek et al., 2013). The knee flexors are ostensibly more susceptible to  
240 muscle damage than the knee extensors following eccentric exercise (Chen, Lin, Chen, Lin, &  
241 Nosaka, 2011). Thus, it may be more pertinent to investigate the hamstrings and recovery,  
242 especially when considering the high injury rate of the knee flexors in sport, e.g., soccer  
243 (Ekstrand et al., 2011). These methodological differences make comparisons difficult to make  
244 between this current study and the previous literature.

245 The reductions in peak torque in the present research that were observed in the days post-EIMD  
246 are likely due to a combination of the mechanical disruptions and subsequent oxidative stress  
247 elicited by the exercise protocol. The high levels of oxidative stress typically observed  
248 following EIMD, including similar protocols to the one utilised in the current study (Nikolaidis  
249 et al., 2007), can cause the muscle to enter an oxidised state, limiting contractile capability  
250 (Powers & Jackson, 2008). However, although CF have been shown to blunt exercise-induced  
251 oxidative stress (Davison et al., 2012), the high variability between individuals in regard to the  
252 level of oxidative stress seen in response to exercise must be considered when interpreting  
253 these findings (Mullins et al., 2013). Additionally, it is unlikely that CF outcompete the existing  
254 antioxidant defence system. Instead, epicatechin and catechin metabolites may upregulate the  
255 endogenous antioxidant enzymes rather than act directly on ROS (Ruijters, Weseler, Kicken,  
256 Haenen, & Bast). Nonetheless, such effects require confirmation with future research.

257 Therefore, with the previous in mind, and as no markers of oxidative stress were taken, it is  
258 difficult to conclude that the large effect sizes seen between CF1245 and CON for MVIC60%,  
259 MVIC30 and MVIC30% at 24 and 48 hr post-EIMD ( $d \geq 0.8$ ) are a result of CF reducing  
260 oxidative damage. Hence, more research is required to understand the potential benefits of CF  
261 as a recovery aid.

262 For subjective measures of muscle soreness it was hypothesised that CF consumption may  
263 reduce muscular soreness *via* the inhibition of pro-inflammatory cytokines, which are  
264 associated with neuropathic pain (Zhang & An, 2007). This was not the case in the present  
265 study, as subjective measures did not differ between groups. However, a large effect size was  
266 observed between CF<sub>1245</sub> and CON for VAS at 48 hr post-EIMD (difference of 31 mm,  $d=0.9$ ).  
267 The inflammatory process begins immediately following muscle damaging exercise, further  
268 developing in the subsequent 24-48 hr if the disruption is significant (Saxton, Claxton, Winter,  
269 & Pockley, 2003). As the peak rate of absorption for CF is ~30 min post-ingestion, it is feasible  
270 that the acute dose of 1245mg CF could reduce the immediate increase in cytokines and other  
271 inflammatory mediators (e.g., neutrophils) that propagate following exercise. Because these  
272 mediators have the capacity to exacerbate muscle damage (Paulsen et al., 2012; Pizza, Peterson,  
273 Baas, & Koh, 2005; Toumi & Best, 2003) and delay recovery in the subsequent days, an early  
274 reduction in this response could lead to an enhanced recovery. This effect may result from the  
275 inhibitory potential of CF monomers on tumour necrosis factor- $\alpha$ , a pro-inflammatory cytokine  
276 involved in muscle lysis (Liao, Zhou, Ji, & Zhang, 2010; Mao, van de Water, Keen, Schmitz,  
277 & Gershwin, 2002). Nonetheless, these are speculative mechanisms that require confirmation  
278 from further research that includes a comprehensive array of inflammation mediators. Our  
279 inability to measure these in the present study is acknowledged as a limitation of the work.

280 This study is not without its limitations, firstly, even though menstrual cycle was accounted for  
281 through the use of self-report questionnaires; they are not as accurate as hormonal tests to

282 appropriately determine cycle phase (Wideman, Montgomery, Levine, Beynnon, & Shultz,  
283 2013). However, hormone analysis was not feasible for the current research. Secondly, it is  
284 possible that the interindividual variability associated with muscle damage (Damas, Nosaka,  
285 Libardi, Chen, & Ugrinowitsch, 2016) and variability between sex responses to EIMD  
286 (Sewright, Hubal, Kearns, Holbrook, & Clarkson, 2008) reduced the power of this study when  
287 paired with relatively small groups. Thirdly, no inflammatory or oxidative stress markers were  
288 taken, thus it was not possible to ascertain whether the intervention did in fact reduce these  
289 markers. Future research should look to include these measures and investigate the effect of  
290 CF supplementation on repeated bouts of high-intensity exercise separated by short recovery  
291 times to better reflect competition patterns typical of team-sport athletes.

292 In conclusion, there is no significant benefit for muscle recovery when comparing an acute  
293 dose of either 830 and 1245 mg CF to a nutrient matched carbohydrate-protein control.  
294 However, this needs to be confirmed with future research, whilst addressing the limitations  
295 above, to confirm or refute any benefits CF supplementation may have following a dose >1000  
296 mg. Research should focus on CF impact on repeat performance and a more comprehensive  
297 study investigating sex differences following CF supplementation should be conducted.

298

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303 the data for the manuscript. All authors aided with the writing, reading and approval of the final  
304 version of this original manuscript.

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### 306 **Conflicts of Interest**

307 No conflicts of interest exist with any of the authors and no funding was received

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444 Tables

Table 1. Participant characteristics

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Group	Age $\pm$ years	Stature $\pm$ cm	Mass $\pm$ kg
CON	24 $\pm$ 4	175 $\pm$ 8	74 $\pm$ 15
CF <sub>830</sub>	25 $\pm$ 5	168 $\pm$ 9	68 $\pm$ 10
CF <sub>1245</sub>	24 $\pm$ 5	168 $\pm$ 11	65 $\pm$ 12

*Note: Data is presented as mean  $\pm$  standard deviation. No significant differences observed between groups.*

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Table 2. Nutritional information of beverages

	kcal/kj	CHO (g)	Pro (g)	Fat (g)	Flavanol (mg)	ORAC
CON	340/1427	61.9	19	1.9	Nil	Nil
CF <sub>830</sub>	366/1531	63.3	21.4	2.9	830	20,000
CF <sub>1245</sub>	379/1589	64	22.6	3.4	1245	30,000

*Note: All drinks contain 60 g of maltodextrin and 25 g chocolate smooth whey protein powder, drinks 2 & 3 contain 10 g and 15 g of Chococru powder respectively; ORAC = oxygen radical absorbance capacity.*

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Table 3. Dietary intake between groups

	CON	CF <sub>830</sub>	CF <sub>1245</sub>	Significance ( <i>P</i> )
Energy (kcal)	2137 ± 559	2101 ± 394	2164 ± 591	0.98
Protein (g)	109 ± 49	106 ± 47	106 ± 43	0.99
CHO (g)	227 ± 46	253 ± 41	265 ± 106	0.60
Fat (g)	93 ± 32	81 ± 19	79 ± 21	0.57

*Note: Group mean ± SD*

Table 4. Changes in MVIC following EIMD

Measure	Group	Time post-EIMD (hr)				
		Baseline	0	24	48	72
MVIC 60 (Nm)	CON	92 ± 23	79 ± 24	71 ± 18	62 ± 21	69 ± 22
	CF <sub>830</sub>	95 ± 30	87 ± 26	83 ± 30	77 ± 31	86 ± 34
	CF <sub>1245</sub>	94 ± 42	74 ± 30	87 ± 37	77 ± 30	79 ± 33
MVIC 30 (Nm)	CON	97 ± 29	88 ± 28	82 ± 21	68 ± 17	81 ± 26
	CF <sub>830</sub>	102 ± 35	99 ± 36	93 ± 34	89 ± 33	98 ± 40
	CF <sub>1245</sub>	104 ± 44	87 ± 33	91 ± 34	86 ± 28	91 ± 31

*Notes: Group mean  $\pm$  SD*

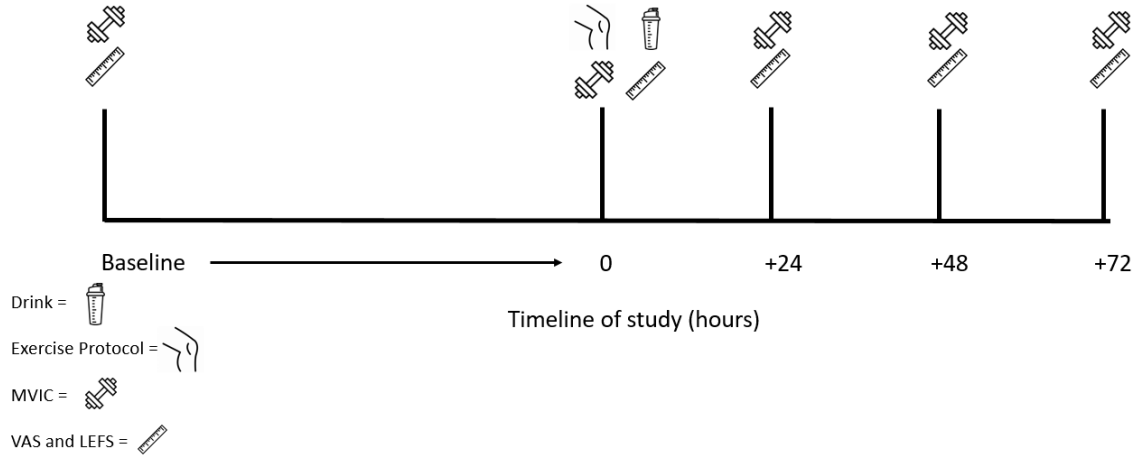
Table 5. Changes in perceived soreness post-EIMD

Measure	Group	Time post-EIMD (hr)				
		Baseline	0	24	48	72
	CON	5 $\pm$ 8	76 $\pm$ 46	96 $\pm$ 42	131 $\pm$ 28	74 $\pm$ 28
VAS (mm)	CF <sub>830</sub>	10 $\pm$ 13	45 $\pm$ 32	79 $\pm$ 26	124 $\pm$ 28	95 $\pm$ 34
	CF <sub>1245</sub>	6 $\pm$ 9	72 $\pm$ 40	72 $\pm$ 38	100 $\pm$ 44	83 $\pm$ 57
	CON	79 $\pm$ 1	67 $\pm$ 12	63 $\pm$ 15	55 $\pm$ 14	66 $\pm$ 6
LEFS (a.u.)	CF <sub>830</sub>	77 $\pm$ 2	72 $\pm$ 3	66 $\pm$ 8	54 $\pm$ 10	63 $\pm$ 8
	CF <sub>1245</sub>	77 $\pm$ 4	65 $\pm$ 10	67 $\pm$ 10	62 $\pm$ 12	68 $\pm$ 7

*Notes: Group mean  $\pm$  SD*

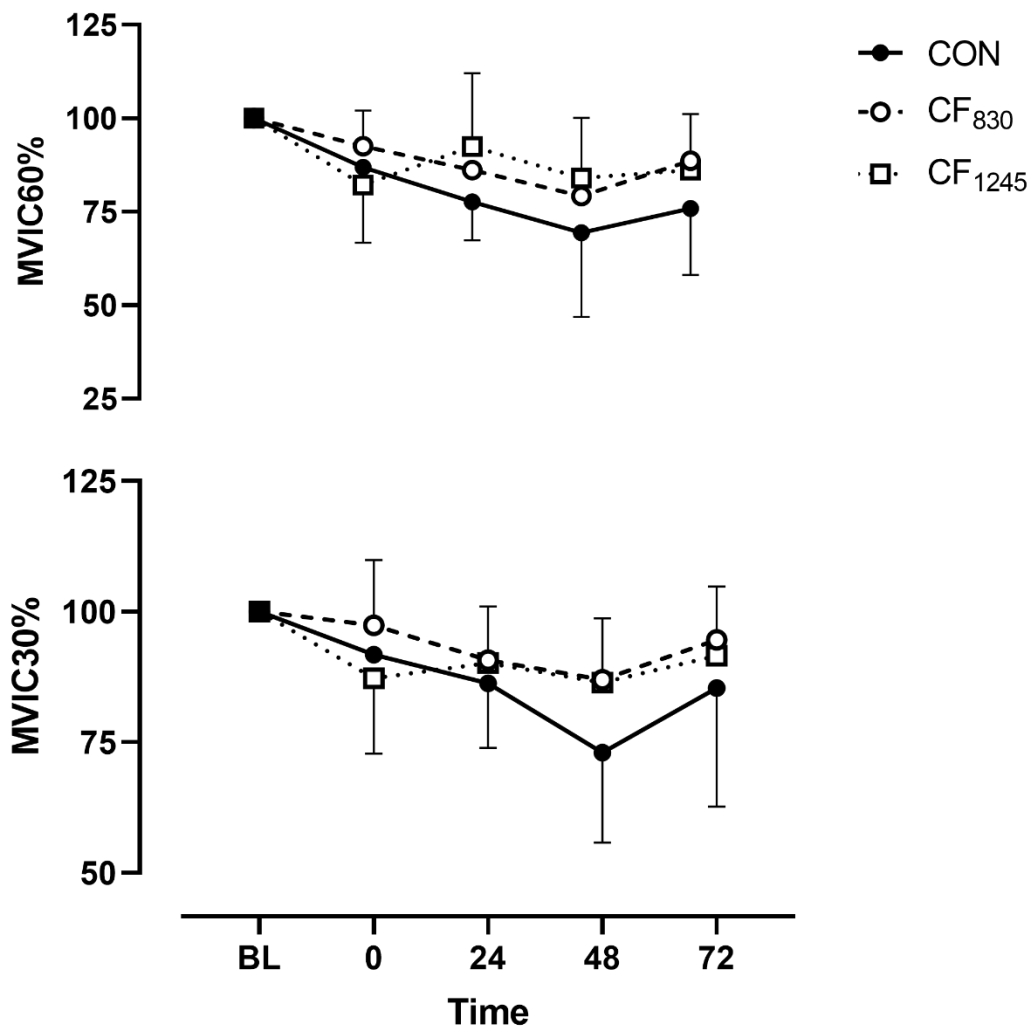
454 **Figures**

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457 **Figure 1.** Study schematic detailing experimental timeline



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459 **Figure 2.** Percentage change from baseline for MVIC following EIMD

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