

1 Title: High-intensity interval walking in combination with acute green tea extract
2 supplementation reduces postprandial blood glucose concentrations in physically inactive
3 participants.

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19 **Abstract**

20 **Background:** Exercise and green tea supplementation have been shown to have the potential
21 to improve postprandial blood glucose concentrations, but past interventions have not often
22 investigated attainable and time effective exercise protocols.

23 **Aim:** The purpose of this study was to investigate the effects of interval walking exercise and
24 acute green tea extract supplementation on the glycaemic response to an oral glucose
25 tolerance test (OGTT).

26 **Methods:** Twelve physically inactive participants (9 male, 3 female, age: 22 ± 1 y; body
27 mass: 81.2 ± 16.3 kg; stature: 175.7 ± 9.6 cm; body mass index (BMI; in kg/m^2): 26.2 ± 4.3)
28 underwent a 2-hour OGTT immediately following i) no intervention (REST), ii) placebo and
29 exercise (EX-PLAC), ii) green tea extract supplementation and exercise (EX-GTE), in a
30 random order. The walking exercise consisted of 6 x 1-min of brisk walking (7.92 ± 0.56
31 km/h) separated by 1-min of slower walking (4.8 km/h). Differences between groups were
32 identified using magnitude based inferences.

33 **Results:** The EX-GTE intervention resulted in a ~9% most likely beneficial effect on blood
34 glucose area under the curve response to the OGTT (702.18 ± 76.90 $\text{mmol/L}^{-1} \cdot 120 \text{ min}^{-1}$)
35 compared to REST (775.30 ± 86.76 $\text{mmol/L}^{-1} \cdot 120 \text{ min}^{-1}$), and a very likely beneficial effect
36 compared to the EX-PLAC (772.04 ± 81.53 $\text{mmol/L}^{-1} \cdot 120 \text{ min}^{-1}$).

37 **Conclusion:** These data suggest that an EX-GTE intervention can reduce postprandial
38 glucose concentrations in physically inactive individuals.

39 **Key words:** Interval training, nutrition, blood glucose, supplement, green tea, walking

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41 **Introduction**

42

43 Glycaemic control is vital in the management and prevention of insulin resistant related
44 diseases such as metabolic syndrome and type 2 diabetes mellitus (T2DM) (American
45 Diabetes Association, 2015). Control of postprandial hyperglycaemia is essential for
46 achieving long-term glycaemic control, defined using recommended HbA_{1c} goals. Peak
47 glucose concentrations typically occur ~60-90 min postprandially and, in individuals with
48 insulin resistance, are sustained for several hours (American Diabetes Association, 2015).
49 Glycaemic excursions, such as those following meals, correlate with HbA_{1c} levels and have a
50 detrimental effect, inducing oxidative stress and inflammation (Brownlee, 2005).
51 Furthermore, HbA_{1c} levels are directly associated with increased cardiovascular disease
52 (CVD) risk and all cause-mortality (Brownlee, 2005); with CVD accounting for more than
53 65% of all diabetic deaths (Lloyd-Jones et al., 2009). T2DM prevalence continues to increase
54 among the adult population and presents a major public health challenge (Zghebi et al.,
55 2017).

56

57 Obesity and a sedentary lifestyle are modifiable risk factors for the development of T2DM.
58 Lifestyle interventions (exercise and diet modification) are therefore obvious cost-effective
59 methods to prevent the development of T2DM and obesity. Both resistance and endurance-
60 based exercise increase whole-body glucose uptake (Koopman et al., 2005; Larsen et al.,
61 1997). However, a major barrier to exercise participation and adherence is reported 'lack of
62 time', regardless of sex, age, socioeconomic status, and fitness level (Troost et al., 2002).
63 Low-volume high-intensity interval training (HIT) has been shown to be a time-efficient
64 stimulus to improve blood glucose in healthy and insulin resistant individuals, via a number

65 of different modalities (Adams, 2013). Little et al. (2011) conclude that HIT training
66 increases muscle mitochondrial capacity and GLUT-4 protein content, rapidly improving
67 glucose control (10 x 60-s cycling bouts). Additionally, regular HIT training (two weeks
68 cycling intervention) may reduce obesity risk, by increasing energy expenditure and fat
69 oxidation, enhancing weight loss, aiding in the prevention of T2DM (Whyte et al., 2010).
70 Lower intensity interval training, such as interval-walking has also been found to be a
71 feasible training method in T2DM participants. Karsoft et al. (2013) report high adherence
72 rates ($89 \pm 4\%$) and significant improvements in $\dot{V}O_{2\max}$ ($16.1 \pm 3.7\%$) and glycaemic control.
73 Moreover, Francois et al. (2014) found that even brief bouts of incline walking (6 x 1 min
74 bouts at $\sim 90\%$ HR_{\max}) prior to meals significantly improved glycaemic control in individuals
75 with insulin resistance.

76

77 Pragmatic lifestyle interventions combining physical activity and diet modifications are
78 effective at promoting weight loss, and improve glycaemic control, potentially reducing the
79 risk of developing T2DM and cardiovascular disease (Hordern et al., 2012). However, there
80 is a need for more research to establish optimal strategies that are both cost-effective and
81 attainable. Interestingly, after investigating diabetic patients' perceptions of illness and
82 treatments, Broadbent et al. (2011) report that 86% of patients adhered to medication,
83 whereas, just 22% report to adhere to nutritional advice. Suggesting that nutritional
84 supplementation may be an effective alternative to diet manipulation. Recent research has
85 found that green tea catechin (GTC) supplementation in humans may improve risk factors
86 related to metabolic syndrome, including increased insulin sensitivity and reduced cholesterol
87 and adiposity (Bogdanski et al., 2012; Suliburska et al., 2012). An accessible concentrated
88 form of the catechins that are linked to lower disease risk (Kao et al., 2006) can be found in
89 green tea extract (GTE). Specifically, the most biologically active molecule in GTE,

90 epigallocatechin gallate (EGCG), is of a high concentration, accounting for ~50-80% of the
91 total catechin content (Khan and Mukhtar, 2007). Importantly, a recent meta-analysis
92 concluded that GTC ingestion lowers fasting blood glucose (-1.48 mg/dL; 95% CI: -2.57, -
93 0.40 mg/dL) in human adults (n = 1584) (Zheng et al., 2013), and Venables et al. (2008) have
94 reported that just 24-hrs of green tea extract (GTE) supplementation improves glycaemic
95 control (-15 ± 4% serum insulin AUC) after an oral glucose load in healthy men (n =11) at
96 rest.

97

98 There is limited research on the use of GTE in combination with exercise. A single study has
99 reported that GTE supplementation attenuates the glucose and insulin responses to an oral
100 glucose load 1 hr after a graded exercise test but not at rest (Martin et al., 2016). The exercise
101 employed by Martin et al. (2016) was also appropriate to control workload between
102 conditions and analyse substrate oxidation. However the translation of results from such an
103 exercise may be limited, as individuals are unlikely to complete a graded exercise test within
104 their regular physical activity for practical and comfort reasons. Further work is needed to
105 build upon this proof of principle research of Martin et al. (2016), and examine if the results
106 from laboratory tests hold true for more attainable and time efficient physical activity such as
107 low-volume interval-walking. The aim of this study was to examine the effect of interval-
108 walking exercise, and any additive effects of GTE, on glycaemic control.

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113 **Materials and methods**

114

115 **Participants**

116 Twelve participants (9 male, 3 female, age: 22 ± 1 y; body mass: 81.2 ± 16.3 kg; stature:
117 175.7 ± 9.6 cm; body mass index (BMI; in kg/m^2): 26.2 ± 4.3) were recruited for the study.

118 All participants were considered to be physically inactive after completing a Global Physical
119 Activity Questionnaire (GPAQ); defined by not meeting national guidelines to achieve a
120 healthy lifestyle – *150 minutes of moderate-intensity exercise per week or 75 minutes of*
121 *vigorous-intensity exercise per week*. All participants gave written informed consent to
122 participate in the study, and the study and its protocol received full ethical approval from the
123 Faculty of Health and Life Sciences Research Ethics Committee at Northumbria University.

124 The study contained no drop out of participants.

125

126 **Preliminary testing**

127 Basic anthropometric measures were taken, as well as safety measures, including, fasting
128 blood glucose (4.41 ± 0.17 mmol/L) and systolic blood pressure (SBP; 124.7 ± 14.3 mmHg)
129 (Omron M6 AC Blood Pressure Monitor, Omron, United Kingdom). Fasting blood glucose
130 was collected following an overnight fast (> 8 hr) using finger capillary blood sampling,
131 followed by blood analysis (Biosen 5030 lactate analyser, Cardiff UK). No participants
132 presented a blood glucose over 7 mmol/L and/or a systolic blood pressure over 160 mmHg.
133 Following recording of preliminary measures, participants completed a graded exercise test
134 on an incline treadmill (Woodway, Waukesha WI). Participants started at 5 km/h and 4%
135 incline, and gradually increased treadmill speed ($1 \text{ km}/\text{h}/\text{min}^{-1}$) and treadmill incline (1

136 $\%/min^{-1}$) in order to achieve a target RPE of 16 (Borg's Perceived Rate of Exertion).
137 Participants wore a Polar Electro heart rate monitor (Polar, Finland) throughout preliminary
138 and intervention exercise testing periods to quantitatively monitor work rate alongside RPE.
139 Average HR was measured as 170 ± 6 bpm after participants achieved an RPE score of 16.

140

141 **Study design**

142 A within-groups, double blind, crossover design was used to compare the effects of green tea
143 extract to a placebo, and to a **resting condition**. A familiarisation visit took place prior to
144 participant completion of three randomly ordered experimental trials. The experimental trials
145 included (1) resting conditions (REST), (2) acute exercise with GTE (EX-GTE), and (3)
146 acute exercise with a placebo (EX-PLAC). All trials were conducted in the morning
147 following an overnight fast (10-12 hrs). At least 3 days separated each trial day (5.7 ± 1.7
148 days), acting as a washout period.

149

150 **Supplementation**

151 Participants were provided with capsules prior to each exercise trial of either decaffeinated
152 GTE powder (EGCg Green Tea Extract, Now Foods, Bloomingdale IL) or a plain-flour
153 placebo to colour match the capsules, and then the opposing capsules the following exercise
154 test day.

155

156 Due to the pharmacokinetic evidence that the bioavailability of ingested catechins is greater
157 in a fasted state (Chow et al., 2005), and considering a half-life of ~ 4 hr (Lee et al., 2002),

158 participants were asked to ingest each capsule with 500 ml of water ~1 hr before the provided
159 dextrose solution, and also ~1 hr before breakfast, lunch and dinner the day prior to each trial
160 day. Therefore, participants ingested a total of 4 GTE capsules, and 4 PLA capsule each.
161 Each 400 mg GTE capsule (98% total polyphenols, 80% catechins, 50% EGCG) contained
162 320 mg of catechins per capsule.

163

164

165 **Study controls**

166 Participants were asked to maintain a habitual diet, and to not consume alcohol or excessive
167 amounts of caffeine the day before each trial. A 24-hr food diary was completed by each
168 participants on these days to monitor intake. Participants were also asked not to perform any
169 exercise the day prior to each trial.

170

171 **Experimental protocol**

172 The resting trial consisted of a 5-minute sitting rest period followed by a 2-hr oral glucose
173 tolerance test (OGTT). OGTT protocol involved a baseline capillary blood sample (minute 0)
174 followed by the ingestion of a 250 ml 75g oral glucose beverage (Dextrose powder,
175 MyProtein Ltd., Cheshire UK) in a fasted state (10-12 hr overnight fast), then capillary blood
176 sampling for 2 hrs following ingestion (at minutes 15, 30, 45, 60, 90, 120).

177

178 After preliminary testing, each participant's treadmill speed and incline was noted, after
179 achieving an RPE score of 16 (speed: 7.92 ± 0.56 km/h; incline 6.88 ± 1.17 %). The trial

180 exercise protocol consisted of 6 x 1-min long bouts at a speed that elicited an RPE of 16,
181 interspersed with ‘slow’ walking (4.8 km/h (3 mph)) for 1-min (total exercise time = 12
182 mins). This exercise protocol was modified from the work of Francois et al. (2014), who
183 found ‘exercise snacking’ to be a time-efficient and effective approach to improve glycaemic
184 control. RPE was used as a simple and inexpensive alternative to HR_{max} as it is easier to
185 measure in a real-world setting. This study aimed for participants to achieve an RPE score of
186 16 (hard - very hard) to mimic the research of Francois et al. (2014) which targeted a measure
187 of 90% HR_{max} . A typical RPE response in the Francois et al. (2014) study resulted in the
188 mean RPE of 16 in high-intensity bouts 4-6, this is in accordance with the work of Francois
189 and Little (2015) which suggests its take ~3-4 intervals to accurately determine intensity.
190 Following the exercise bout, a baseline blood glucose sample was taken prior to the
191 administration of the oral glucose load and 2-hr OGTT.

192

193 **Statistical analysis**

194 A sample size calculation was conducted using a custom made spreadsheet (Will Hopkins;
195 www.sportsci.org), based on glucose AUC reproducibility data from previous work (Gordon
196 et al., 2011), who found increases greater than $63.5 \text{ mmol/L}^{-1} \cdot 120 \text{ min}^{-1}$ and decreases greater
197 than $80.9 \text{ mmol/L}^{-1} \cdot 120 \text{ min}^{-1}$ to exceed daily variation. A between subject standard deviation of
198 $100 \text{ mmol/L}^{-1} \cdot 120 \text{ min}^{-1}$ was taken from Venables et al. (2008), and a within subject standard
199 deviation of $98 \text{ mmol/L}^{-1} \cdot 120 \text{ min}^{-1}$ was calculated by taking 13% (upper 95% CI of normal
200 daily variation; Gordon et al., 2011) of the average glucose AUC reported by Venables et al.
201 (2008). These values resulted in a sample size of ten being required to achieve 90% power.

202

203 Glucose area under the curve (AUC) was calculated using the incremental method. All data
204 were log-transformed prior to analysis. The descriptive summary for all variables comprised
205 of the geometric mean and dispersion shown as standard deviation (SD) (Hopkins et al.,
206 2009). An analysis of variance (ANOVA) model was used on peak and AUC glucose data.
207 Following this, a magnitude-based inferences approach (Hopkins et al., 2009), was used to
208 analyse the mean effect of the intervention (EX-GTE), versus placebo (EX-PLAC) and rest
209 (REST). Inferences were based on the disposition of the 90% confidence limits (CL) for the
210 mean difference to the minimal clinically important difference (MCID). Log-transformed
211 data were back transformed to provide percent differences between conditions. The
212 probability (percent chances) that differences in glucose AUC between EX-GTE, EX-PLAC
213 and REST were beneficial (>MCID), harmful (>MCID with opposite sign), or trivial (within
214 \pm MCID) was calculated (Hopkins et al., 2009). Robust clinical data for the MCID on all
215 variables is scarce, therefore, MCID was determined using a standardised mean difference of
216 0.2 times between subjects' standard deviations (Cohen, 1988). Subsequently, the percent
217 chances were defined via probabilistic terms assigned using the following scale; <0.5%, most
218 unlikely or almost certainly not; 0.5 to 5%, very unlikely; 5 to 25%, unlikely or probably not;
219 25 to 75%, possibly; 75 to 95%, likely or probably; 95 to 99.5%, very likely; >99.5%, most
220 likely or almost certainly (Batterham and Hopkins, 2006). Inferences were categorised as
221 clinical, with the default probabilities for declaring an effect clinically beneficial being <0.5%
222 (most unlikely) for harm and >25% (possibly) for benefit (Hopkins et al., 2009).
223 Additionally, in the case of an effect being possibly beneficial (>25%) an unacceptable risk
224 of harm (>0.5%) and with an odds ratio for benefit: harm of <66, would be classified as
225 unclear.

226

227

228 **Results**

229

230 The heart rate (170 ± 13 vs. 166 ± 13 beats.min⁻¹) and RPE (13 ± 2 vs. 14 ± 2) were
231 comparable between exercise trials. Comparison between conditions for glucose AUC and
232 peak glucose can be seen in Table 1. When compared to the REST condition (775.30 ± 86.76
233 mmol/L⁻¹.120 min⁻¹), there was a most likely beneficial effect of EX-GTE (702.18 ± 76.90
234 mmol/L⁻¹.120 min⁻¹) on glucose AUC and a very likely beneficial effect compared to EX-
235 PLAC (772.04 ± 81.53 mmol/L⁻¹.120 min⁻¹). The effect was unclear between EX-PLAC and
236 REST. **The average response to the OGTT at all time points is presented in Fig 1.** There was
237 a very likely beneficial effect of EX-GTE (7.51 ± 0.91 mmom/L) when compared to REST on
238 peak glucose (8.30 ± 0.92 mmol/L). The effect was unclear on all other outcomes.

239

240 [Insert Figure 1.]

241

242 **Discussion**

243

244 This study aimed to investigate the effect of high-intensity walking exercise on glycaemic
245 control, and any additive effect of an acute GTE supplementation strategy. The main finding
246 was that the walking exercise alone did not influence the glycaemic response during a 2-h
247 OGTT, but the combined walking exercise with GTE had a 'most likely', and 'very likely'
248 beneficial effect on glucose AUC and peak glucose respectively.

249

250 Previous research has suggested that high-intensity interval walking may be effective at
251 reducing mean postprandial blood glucose concentrations (Francois et al., 2014; Jakobsen et
252 al., 2016). Francois et al. (2014) reported that 6 x 1 min bouts of inclined interval walking
253 (90% HR_{max}) interspersed with periods of slow walking significantly reduced mean 3 hr
254 postprandial glucose before breakfast (-1.4 ± 1.5 mmol/L, $p = 0.02$) when compared to
255 traditional continuous exercise (30 min moderate-intensity; 60% HR_{max}), a 17% reduction in
256 3 hr post-breakfast AUC (interval walking: $1,090 \pm 178$ mmol/l vs. continuous exercise:
257 $1,307 \pm 337$, $p = 0.04$). The present study aimed to emulate the exercise protocol of Francois
258 et al. (2014) whilst using RPE to measure effort, as opposed to HR_{max}, to give a reliable
259 (Ciolac et al., 2015) but simple and inexpensive method that could be replicated more easily
260 in the real world, to simplify the translation of our findings to practice. However, this study
261 did not find a worthwhile effect between postprandial glucose concentrations of exercise
262 alone with placebo and the resting condition. More specifically, we aimed for participants to
263 achieve an RPE score of 16 throughout exercise testing, in an attempt to replicate the 90%
264 HR max targeted by Francois et al. (2014). However, average trial RPE failed to give the
265 desired effect (RPE = 16) with an average RPE score of 13.4 ± 1.7 (HR: 170 ± 13.1 bpm) and
266 13.7 ± 1.6 (HR: 165.8 ± 13 bpm) during the EX-PLAC and EX-GTE trials, respectively.
267 Moreover, the average HR during the high-intensity intervals was 170 ± 6 , ~85% of HR_{max},
268 lower than the desired 90% of HR_{max} (~178 bpm, $p < 0.01$). This suggests that the study
269 duration, and/or intensity may not have been high enough to induce the desired physiological
270 changes. Similarly, Jakobsen et al. (2016) suggest that altering the intervention to 3 min long
271 bouts of high-intensity walking may improve glycaemic control, specifically, by reducing
272 postprandial glucose concentrations. The study found no difference between mean glucose
273 after 1 min walking cycles compared to control, whereas 3 min bouts attenuated glucose
274 response following a 4 hr liquid mixed meal tolerance test. The inclusion of a step test in

275 place of a ramp test would be recommended in future, with sufficient breaks between steps to
276 reduce the effect of cumulative fatigue during the graded exercise test and increase the
277 walking speed at an RPE of 16. Whilst the current study found no benefit to high-intensity
278 interval walking alone for glycaemic control, these results are contrary to the limited previous
279 research.

280

281 The addition of GTE to the walking intervention did reduce postprandial glucose
282 concentrations, and the ~9% reduction in glucose AUC in the EX-GTE trial can be
283 interpreted as being ‘most likely beneficial’ compared to REST and ‘very likely beneficial’
284 compared to exercise alone (Table 1). The effect of this intervention was greater than the
285 typical 6% daily variation of OGTT results identified by Gordon et al. (2011). This would
286 suggest that the study intervention may improve insulin sensitivity of the skeletal muscle,
287 agreeing with the work of Martin et al. (2016) who suggest that GTE may alter skeletal
288 muscle glucose uptake in humans. Possibly due to the increased translocation of glucose
289 transporters which is apparent in rodent studies, specifically, green tea has shown to have a
290 similar effect to exercise, in that, prolonged consumption increases GLUT-4 translocation in
291 normal and insulin resistant skeletal muscle, in addition to increased adipocyte insulin-
292 receptor binding (Wu et al., 2004).

293

294 A limitation of the present study is the absence of a GTE group without the exercise
295 intervention to give further context to the combined effect of GTE and exercise, however,
296 previous research has indicated that GTE alone may not sufficiently reduce postprandial
297 glucose concentrations. As mentioned, Martin et al. (2016) state that GTE attenuated glucose
298 response to an oral glucose load following acute exercise, however, the study found no effect

299 under resting conditions (Glucose AUC: GTE = 394 ± 70 , PLA = 409 ± 78 mmol/L⁻¹·60 min⁻¹,
300 ¹, p = 0.51). Venables et al. (2008) also found that GTE significantly lowered insulin AUC (-
301 $15 \pm 4\%$, p < 0.01) and increased insulin sensitivity (insulin sensitivity index (ISI): $13 \pm 4\%$,
302 p < 0.05), albeit with no difference in glucose concentrations (p > 0.05). Furthermore, a
303 combined intervention should be recommended where possible due to the further reaching
304 benefits of physical activity. Importantly, this study presents evidence that a combined
305 walking and GTE intervention can improve glycaemic control. This offers insight in to a
306 potentially more real world applicable and achievable exercise in physically inactive people
307 than has been researched in the past, as previous studies have for example used higher
308 intensity cycling protocols (Little et al., 2011; Whyte et al., 2010). It should also be
309 considered when interpreting our results that although the participants were physically
310 inactive, their glycaemic control was good under all testing conditions, and fasted blood
311 glucose was 4.41 ± 0.17 mmol/L. The results may be different in populations with poorer
312 glycaemic control, and further research is warranted in this area.

313

314 In conclusion low-volume interval-walking exercise combined with GTE supplementation
315 was found to reduce postprandial glucose concentrations in physically inactive individuals. A
316 combined walking and green tea routine may be an achievable and translatable intervention
317 for physically inactive people.

318

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321

322 **Authors' contributions**

323 XXX and XXX conceived the study. XXX recruited participants and collected the data. XXX
324 performed the statistical analysis. XXX, XXX and XXX contributed to drafts of the manuscript, and
325 all authors have read and approved the final version of the manuscript, and agree with the order of
326 presentation of the authors.

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328

329 **Availability of data and materials**

330 The datasets used and/or analysed during the current study are available from the
331 corresponding author on reasonable request.

332

333 **Declaration of conflicting interests**

334 The authors declared no potential conflicts of interest with respect to the research, authorship,
335 and/or publication of this article.

336

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434 Figure caption

435 **Fig 1.** Average post-prandial blood glucose (mmol/L) response at each time point of the OGTT
436 for the REST, EX-PLAC and EX-GTE conditions. Error bars for EX-PLAC have been removed for
437 clarity.

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454 **Table 1 Clinical inferences of differences in glycaemic control between treatment groups**

Variable	Comparison	Difference between groups (% mean; 90%CL)	Likelihood (%) of intervention being beneficial / trivial / harmful	Clinical inference
Glucose AUC (mmol.min ⁻¹)	EX-GTE to REST	-9.4 ±4.9	99.8 / 0.1 / 0.1	Most likely beneficial
	EX-GTE to EX-PLAC	-9.1 ±7.1	98.0 / 0.0 / 2.0	Very likely beneficial
	EX-PLAC to REST	-0.37 ±50	50.5 / 0.0 / 2.0	Unclear
Peak glucose (mmol/l)	EX-GTE to REST	-9.8 ±7.5	98.2 / 0.0 / 1.7	Very likely beneficial
	EX-GTE to EX-PLAC	-7.23 ±12	84.1 / 0.2 / 15.2	Unclear
	EX-PLAC to REST	-2.79 ±50	53.7 / 0.1 / 46.2	Unclear

AUC = area under the curve; REST = resting condition; EX-PLAC = exercise intervention with placebo; EX-GTE exercise intervention with green tea extract supplementation

