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**No acute effect of reduced-exertion high intensity interval training (REHIT) on insulin sensitivity**

Metcalfe RS<sup>134</sup>, Fawkner SG<sup>24</sup> & Vollaard NBJ<sup>34\*</sup>

*1 School of Sport, Ulster University, Northern Ireland, UK*

*2 School of Physical Education, Edinburgh University, Edinburgh, UK*

*3 Department for Health, University of Bath, Bath, UK*

*4 School of Life Sciences, Heriot-Watt University, Edinburgh, UK*

\*Corresponding Author

Dr Niels Vollaard

Department for Health

University of Bath

Bath, BA2 7AY, UK

Phone: 01225 384649

Email: n.vollaard@bath.ac.uk

1 **ABSTRACT**

2

3 We have previously demonstrated that reduced-exertion high-intensity interval training  
4 (REHIT), requiring a maximum of two 20-s all out cycling sprints in a 10-min exercise session,  
5 improves insulin sensitivity in sedentary men over a 6-week training intervention. However,  
6 the acute effects of REHIT on insulin sensitivity have not previously been described. In this  
7 study fourteen men and women (mean±SD age: 23±5 y; BMI 22.7±4.7 kg·m<sup>-2</sup>;  $\dot{V}O_2$ max:  
8 37.4±8.6 mL·kg<sup>-1</sup>·min<sup>-1</sup>) underwent oral glucose tolerance testing 14-16 hours after an acute  
9 bout of reduced-exertion high-intensity interval training (2 x 20-s all-out sprints; REHIT),  
10 moderate-vigorous aerobic exercise (45 minutes at ~75%  $VO_2$ max; AER), and a resting  
11 control condition (REST). Neither REHIT nor AER were associated with significant changes  
12 in glucose AUC (REHIT 609±98 vs. AER 651±85 vs. REST 641±126 mmol·l<sup>-1</sup>·120 min), insulin  
13 AUC (REHIT 30.9±15.4 vs. AER 31.4±13.0 vs. REST 35.0±18.5 nmol·l<sup>-1</sup>·120 min) or insulin  
14 sensitivity estimated by the Cederholm index (REHIT 86±20 vs. AER 79±13 vs. REST 82±24  
15 mg·l<sup>-2</sup>·mmol<sup>-1</sup>·mU<sup>-1</sup>·min<sup>-1</sup>). These data suggest that improvements in insulin sensitivity  
16 following a chronic REHIT intervention are the result of training adaptations rather than acute  
17 effects of the last exercise session.

## 18 INTRODUCTION

19

20 The finding that lack of time is a major barrier to performing regular exercise has led to a rise  
21 in studies investigating high-intensity interval training (HIT) as a time-efficient method for  
22 improving aerobic fitness and metabolic health [16]. However, it is noteworthy that due to the  
23 required recovery intervals the time-commitment of most HIT protocols is generally similar to  
24 current guidelines for aerobic exercise. We [26] and others [18] have recently demonstrated  
25 that a modified HIT protocol requiring two or three 20-s Wingate sprints in a 10-min cycling  
26 session (reduced-exertion HIT; REHIT) can improve aerobic capacity in sedentary men and  
27 women, and insulin sensitivity in men. These benefits were observed despite the low total  
28 time-commitment (30 min per week) and manageable ratings of perceived exertion,  
29 suggesting that REHIT may be a suitable alternative or adjunct to current exercise  
30 recommendations [26]. However, more studies are required to further characterise the acute  
31 and chronic effects of REHIT on human health and metabolism, both in isolation and in  
32 combination with more traditional exercise modes.

33

34 Insulin sensitivity is an important biomarker in the development of type 2 diabetes and  
35 metabolic syndrome and is a primary target for preventative intervention [8,33]. The effects of  
36 exercise on insulin sensitivity are thought to be largely explained by improved glucose uptake  
37 in skeletal muscles [9,10]. From this perspective, exercise has been shown to exert three  
38 distinct regulatory roles on skeletal muscle glucose uptake. Firstly, skeletal muscle  
39 contractions themselves recruit glucose transporter 4 (GLUT4) molecules to the cell  
40 membrane and increase glucose uptake in an intensity dependent manner, through signalling  
41 pathways that are independent of and additive to insulin [14,29,34,38,41]. This effect is  
42 transient, subsiding completely ~2-3 hours after the cessation of the muscle contractions [24].  
43 However, it appears to be replaced by an acute enhancement of insulin-stimulated recruitment  
44 of GLUT4 and hence postprandial glucose disposal in the exercised muscle, which can be  
45 detected for 24-48 hours post-exercise, and which appears to track with the replenishment of

46 skeletal muscle glycogen stores [2,5,19]. Lastly, the cumulative effect of many repeated bouts  
47 of acute exercise (i.e., exercise training) can bring about a favourable change in skeletal  
48 muscle phenotype and body composition which correlates with a more prolonged increase in  
49 insulin sensitivity that can be detected for several days after the final training bout [9].

50

51 The improvements in insulin sensitivity in men following REHIT have been noted at 3 days  
52 following the final exercise session and were ascribed to chronic training adaptations [18,26].  
53 However, this contention remains unsubstantiated since no study has examined the effects of  
54 a single bout of REHIT on insulin sensitivity. Understanding the role of both single and  
55 accumulated bouts of exercise on parameters of metabolic health is important from the  
56 perspective of exercise prescription. Therefore, the aim of this study was to determine the  
57 impact of a single bout of REHIT on insulin sensitivity measured the following day in  
58 comparison to a bout of moderate-vigorous aerobic exercise and a no-exercise control  
59 condition. Based on the findings of Brestoff et al [3], our primary hypothesis was that there  
60 would be no acute effect of REHIT on insulin sensitivity, whilst our secondary hypothesis  
61 speculated there would be an increase in insulin sensitivity following an acute bout of  
62 moderate-vigorous intensity aerobic exercise.

## 63 MATERIALS AND METHODS

64

### 65 **Participants**

66 Fourteen healthy young men (n=8) and women (n=6) gave their written informed consent to  
67 take part in this study (mean±SD age: 23±5 y; BMI 22.7±4.7 kg·m<sup>-2</sup>;  $\dot{V}O_2$ max: 37.4±8.6 mL·kg<sup>-1</sup>·min<sup>-1</sup>). All participants were sedentary or recreationally active according to the International  
68 Physical Activity Questionnaire. The study was approved by the Heriot-Watt University School  
69 of Life Sciences Ethics Committee and conducted in accordance with the *Declaration of*  
70 *Helsinki* and ethical standards for sport and exercise science research [20].  
71

72

### 73 **Baseline Testing and Familiarisation**

74 Prior to the main trials participants visited the laboratory on four occasions. During the initial  
75 visit maximal oxygen uptake capacity ( $\dot{V}O_2$ max) was determined during an incremental cycling  
76 test to volitional exhaustion on an electrically-braked cycle ergometer (25 W·min<sup>-1</sup> ramp; Lode  
77 Excalibur Sport, the Netherlands) with analysis of  $\dot{V}O_2$  using an online metabolic cart  
78 (SensorMedics, Bilthoven, the Netherlands).  $\dot{V}O_2$ max was taken as the highest value of a 15-  
79 breath rolling average. Participants performed two familiarisation sessions for the REHIT trial  
80 and one for the aerobic exercise trial (AER). The REHIT familiarisation sessions were used to  
81 familiarise participants with the procedures and the effort required during Wingate-type sprints.  
82 The AER session was used to check the intensity predicted to elicit 75%  $\dot{V}O_2$ max. Participants  
83 cycled for 15-min at the prescribed intensity and  $\dot{V}O_2$  was measured continuously throughout  
84 (SensorMedics, Bilthoven, the Netherlands). If necessary, adjustments were made to the  
85 intensity used during the main trials.

86

### 87 **Experimental Procedures**

88 Participants completed three main experimental trials (REHIT, AER and REST) in a  
89 randomised cross-over design, with each trial taking place over a 2-day period. During each

90 trial participants underwent an oral glucose tolerance test (OGTT) on the morning after  
91 performing either: 1) a single bout of REHIT, 2) a single bout of moderate-vigorous intensity  
92 aerobic exercise (AER), or 3) a no-exercise control condition (REST). Each trial was separated  
93 by at least 1 week and prior to each trial participants were asked to refrain from performing  
94 strenuous/prolonged physical activities and consuming alcohol/caffeine for 2 days and 1 day  
95 respectively.

96

97 On the evening prior to each OGTT, participants attended the laboratory between 4:30 pm  
98 and 7:00 pm to perform the exercise session. Participants were given a standardised evening  
99 meal (energy:  $3234 \pm 494$  kJ; carbohydrate:  $107 \pm 17$  g; fat:  $21 \pm 7$  g; protein:  $35 \pm 10$  g) 30 min  
100 after completion of the exercise bout. For each participant the time of attendance was  
101 consistent between conditions. Participants fasted overnight and returned to the laboratory  
102 the following morning between 7:00 am and 9:30 am. An OGTT was performed after 15 min  
103 of seated rest.

104

### 105 ***Exercise Protocols***

106 All exercise protocols were performed on an electrically-braked cycle ergometer (Lode  
107 Excalibur Sport, the Netherlands). The aerobic exercise protocol involved 45 min of cycling at  
108 an intensity predicted to elicit ~75% of  $\dot{V}O_2$ max as previously used by Brestoff et al. [3].  
109 Cadence was self-selected and the exercise was completed in three intervals of 15 min with  
110 2 min of resting recovery in between.  $\dot{V}O_2$  was determined during the final 5 min of the first  
111 bout (SensorMedics, Bilthoven, the Netherlands) and heart rate was measured throughout  
112 (Polar Electro, Vansbro, Sweden). The REHIT condition involved 10 min of unloaded pedalling  
113 and two 20-s Wingate sprints at 3:00 min and 6:40 min as previously described [26]. Just  
114 before each sprint, participants increased their pedal cadence to their maximal speed, a  
115 braking torque was applied to the ergometer ( $0.70$  and  $0.60$   $\text{Nm} \cdot \text{kg}^{-1}$  for men and women,  
116 respectively), and participants sprinted maximally against the braking torque for 20 s.

117 **Oral Glucose Tolerance Test**

118 A fasting blood sample was obtained from a forearm vein by venepuncture using the  
119 vacutainer system, after which 75 g of anhydrous glucose (Fisher Scientific, Loughborough,  
120 UK) in 100 mL of water was orally ingested and further blood samples collected at 60 and 120  
121 min after glucose ingestion. Blood samples were collected into cooled plastic tubes containing  
122 EDTA and stored on ice during the OGTT. Samples were centrifuged for 10 min at 2000 g and  
123 4°C to separate the plasma, which was stored at -20°C until analysis. Plasma glucose  
124 concentration was determined in duplicate with a CV of <1% (YSI Stat 2300, Yellow Spring  
125 Instruments, Yellow Spring, OH). Plasma insulin concentrations were measured in duplicate  
126 using a commercially available ELISA with a CV of 4% (Invitrogen, UK). Area under the curve  
127 (AUC) for plasma glucose and insulin responses was calculated using the trapezoid rule,  
128 whilst insulin sensitivity was determined using the Cederholm Index [6].

129

130 **Statistics**

131 . Statistical analysis was performed using SPSS statistical software. To simplify analysis and  
132 interpretation of an otherwise complex data set, the OGTT responses for each condition were  
133 converted into simple summary statistics (i.e., within subject fasting, total AUC and insulin  
134 sensitivity scores). As two-way repeated measures ANOVAs revealed no gender × group  
135 interactions for any OGTT-derived variables, all data was pooled and comparisons were made  
136 using 1-factor repeated measures ANOVA with *post hoc* Ryan Holm Bonferroni corrected t-  
137 tests if appropriate. Significance was accepted at P<0.05. Exercise characterisation data are  
138 presented as mean ± SD, whilst the effects of the exercise bouts on OGTT-derived variables  
139 is presented in text as the mean change from the REST condition with 95% confidence  
140 intervals. Data in figures are presented as mean ± SD unless otherwise stated.



141 **RESULTS**

142

143 ***Exercise Characteristics***

144 During the AER exercise session participants cycled at  $76\pm 4\%$  of  $\dot{V}O_2\text{max}$  and this elicited  
145  $86\pm 7\%$ ,  $90\pm 6\%$  and  $91\pm 6\%$  of maximal heart rate (HRmax) during bouts 1, 2 and 3  
146 respectively. Peak, mean and minimum power output for REHIT were  $12.2\pm 2.1$ ,  $6.6\pm 1.5$  and  
147  $4.4\pm 1.4 \text{ W}\cdot\text{kg}^{-1}$  for the first sprint, and  $11.9\pm 2.0$ ,  $5.9\pm 1.5$  and  $3.9\pm 1.3 \text{ W}\cdot\text{kg}^{-1}$  for the second  
148 sprint. Heart rate peaked at  $93\pm 4\%$  and  $94\pm 3\%$  of HRmax for the first and second sprints  
149 respectively. The total amount of work performed in the AER and REHIT bouts was  
150  $312.8\pm 118.3$  and  $16.7\pm 5.4 \text{ kJ}$ , respectively.

151

152 ***Glucose and Insulin Responses to the OGTTs***

153 The insulin and glucose responses to the OGTTs are presented in Figure 1. There was no  
154 effect of either exercise condition on fasting glucose concentration (mean change [95% CI's]:  
155 REHIT:  $-0.066 [-0.192, 0.059] \text{ mmol}\cdot\text{l}^{-1}$ ; AER:  $-0.090 [-0.273, 0.093] \text{ mmol}\cdot\text{l}^{-1}$ ) or fasting insulin  
156 concentrations (REHIT:  $-0.006 [-0.021, 0.008] \text{ nmol}\cdot\text{l}^{-1}$ ; AER:  $-0.017 [-0.038, 0.005] \text{ nmol}\cdot\text{l}^{-1}$ ) when  
157 compared with REST. Similarly, neither REHIT or AER were associated with any changes in  
158 glucose AUC (REHIT:  $-32.3 [-77.8, 13.1] \text{ mmol}\cdot\text{l}^{-1}\cdot 120\text{min}$ ; AER:  $+9.38 [-45.9, 64.7] \text{ mmol}\cdot\text{l}^{-1}$   
159  $\cdot 120\text{min}$ ), insulin AUC (REHIT:  $-4.19 [-10.7, 2.28] \text{ nmol}\cdot\text{l}^{-1}\cdot 120\text{min}$ ; AER:  $-3.73 [-8.97, 1.52]$   
160  $\text{nmol}\cdot\text{l}^{-1}\cdot 120\text{min}$ ) or insulin sensitivity (REHIT:  $+4.91 [-0.941, 10.8] \text{ mg}\cdot\text{l}^2\cdot\text{mmol}^{-1}\cdot\text{mU}^{-1}\cdot\text{min}^{-1}$ ;  
161 AER:  $-2.64 [-12.1, 6.86] \text{ mg}\cdot\text{l}^2\cdot\text{mmol}^{-1}\cdot\text{mU}^{-1}\cdot\text{min}^{-1}$ ) when compared with REST.

162 **DISCUSSION**

163

164 The aim of this study was to examine the effect of a single bout of REHIT on insulin sensitivity  
165 measured the following day in comparison to a single bout of moderate-vigorous aerobic  
166 exercise and a no-exercise control condition. In agreement with our primary hypothesis, these  
167 data demonstrate that a single bout of REHIT does not improve insulin sensitivity, and this  
168 strengthens our previous contention that the increase in insulin sensitivity detected 3 days  
169 following a 6-week REHIT intervention in sedentary men can be ascribed to chronic training  
170 adaptations [18,26]. In contrast, our secondary hypothesis was not supported, with no  
171 increase in insulin sensitivity observed following a single bout of moderate-vigorous intensity  
172 aerobic exercise.

173

174 Our finding that there was no acute impact of REHIT on insulin sensitivity is in line with recent  
175 acute studies demonstrating no change in OGTT-derived insulin sensitivity 14-16 hours  
176 following single bouts of HIT consisting of five sprints at ~125%  $\dot{V}O_2\text{max}$  [3] or four 30-s  
177 Wingate sprints [39]. Similarly, HIT did not appear to attenuate the systemic glucose or insulin  
178 response to a high-fat mixed meal challenge administered 14 hours post-exercise, although  
179 the overall lipemic response was reduced [12,13]. Conversely, Ortega et al. [31] reported a  
180 significant increase in insulin sensitivity measured using intravenous glucose tolerance testing  
181 (IVGTT) which lasted for at least 48 hours after four 30-s Wingate sprints, whilst Little et al.  
182 [25] reported a reduction in mean 24-h glucose concentrations and 24-h postprandial glucose  
183 AUC following ten 1-min sprints at >90%  $HR_{\text{max}}$  in a small cohort of overweight men. The  
184 reason for these discrepancies is unclear but may be related to the different methods of  
185 assessing insulin sensitivity and glycaemic control (IVGTT and continuous glucose monitoring  
186 vs. OGTT or oral mixed meals). Further studies are warranted examining the acute effects of  
187 HIT/REHIT, both in isolation and in combination with more traditional exercise modes, on  
188 insulin sensitivity using the gold standard hyperinsulinemic clamp in a range of populations.  
189 Nevertheless, the current data have important implications for the prescription of REHIT (in

190 isolation) as a preventative intervention in the general population. If reductions in postprandial  
191 systemic insulin and glucose concentrations are the primary targeted endpoint then single  
192 bouts will not be effective; rather REHIT needs to be repeated regularly over several weeks in  
193 order for adaptations to be accrued.

194

195 We could detect no increase in insulin sensitivity measured 14-16 hours following an acute  
196 bout of vigorous intensity aerobic exercise. This is in contrast to recent data from Brestoff et  
197 al. [3] who demonstrated a 25% reduction in insulin AUC during an OGTT using a comparable  
198 cohort of participants, exercise bout and post-exercise time point. However, the literature as  
199 a whole is somewhat inconsistent, with many studies in healthy lean individuals reporting no  
200 measurable changes at similar time-points following acute aerobic exercise of varying  
201 intensities and durations [1,2,11,21,35,37], whilst others show improvements for as long as  
202 48 hours post-exercise exercise [27,32,36,40]. The lack of change in our study may be  
203 explained by a combination of two factors. Firstly, the timing and composition of post-exercise  
204 feeding appears to have a strong influence on the response. Several studies show that  
205 restriction of carbohydrate intake appears to prolong any increase in insulin sensitivity post-  
206 exercise both in rodents [5,19,23] and in humans [2,22,30]. This makes sense from an  
207 evolutionary perspective, as any metabolic acceleration following exercise is presumably an  
208 attempt to restore intramuscular substrate stores as quickly as possible so that further exercise  
209 may be performed [7]. Secondly, there is evidence that individuals with lower baseline levels  
210 of insulin sensitivity tend to exhibit a more prolonged increase in post-exercise insulin  
211 sensitivity which can be detected even after several meals have been consumed [4, 11, 15, 28].  
212 This is perhaps reflective of the decrement in insulin action resulting in delayed restoration of  
213 intramuscular substrate stores after exercise, thereby necessitating a more prolonged  
214 increase in insulin sensitivity. In any case, given that our cohort of participants already had a  
215 healthy level of insulin sensitivity, and we fed them a meal containing ~100 g of carbohydrate

216 30 min post-exercise, it is perhaps not all that surprising that we observed no change in insulin  
217 sensitivity following the aerobic exercise bout in the current study.

218

219 There are several limitations to the current analysis which provide opportunity for further study.

220 Firstly, we could only include three time-points during the OGTT for our calculation of insulin

221 sensitivity. Whilst this protocol was sensitive enough to detect the relatively large changes in

222 insulin sensitivity observed following the REHIT training intervention [26], it must be

223 acknowledged that we may have missed more subtle changes in the current analysis. It would

224 therefore be useful to repeat the current study using the more sensitive gold standard

225 euglycemic clamp methodology. Secondly, we only included a 14-16 hour post-exercise time

226 point in this study and cannot therefore rule out that REHIT impacts on insulin sensitivity in

227 the more immediate post-exercise period (i.e., in response to the first feeding). Lastly, in order

228 to be able to make firm comparisons between the current acute study and the previous training

229 intervention [26] we recruited a similar cohort of participants who, although sedentary, were

230 young, lean and with a healthy level of insulin sensitivity. It is therefore necessary to

231 investigate the acute impact of REHIT in populations with insulin resistance, particularly in

232 light of the recent finding that other models of HIT substantially improve glycaemic control in

233 middle aged men presenting with T2D [17].

234

235 To summarise, the data of the present study demonstrate no effect of an acute bout of REHIT

236 on insulin sensitivity. This suggests that the potential utility of REHIT for improving insulin

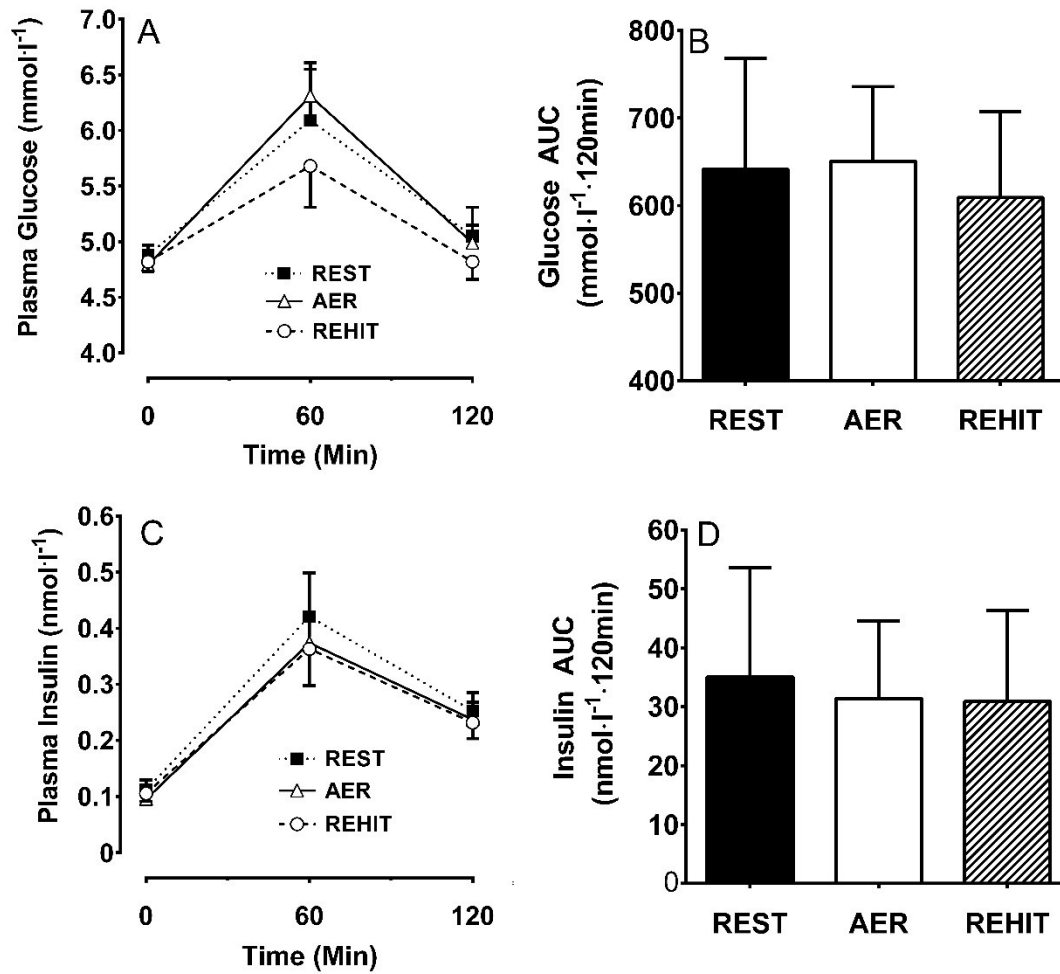
237 sensitivity may be limited to a chronic training response.

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356 **Figure 1** Plasma glucose (A+B) and insulin (C+D) responses to acute exercise. For clarity,  
 357 the responses over time to the OGTT are presented as mean±SEM, whilst the AUC data is  
 358 presented as mean±SD. REHIT: reduced-exertion HIT, AER: aerobic exercise, REST: no  
 359 exercise control.