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Cross-sectional and longitudinal associations between different exercise types and food cravings in free-living healthy young adults

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ABSTRACT

Introduction. An increase in energy intake due to alterations in hedonic appetite sensations may, at least in part, contribute to lower-than-expected weight loss in exercise interventions. The aim of this study was to examine cross-sectional and longitudinal associations between habitual exercise participation and food cravings in free-living young adults.

Methods. A total of 417 adults (49% male, 28±4 years) reported frequency and duration of walking, aerobic exercise, resistance exercise and other exercise at baseline and every 3 months over a 12-month period. Food cravings were assessed via the Control of Eating Questionnaire at baseline and 12-month follow-up.

Results. Cross-sectional analyses revealed more frequent cravings for chocolate and a greater difficulty to resist food cravings in women compared to men ($p<0.01$). Only with resistance exercise significant sex by exercise interaction effects were observed with favorable responses in men but not in women. Significant main effects were shown for walking and aerobic exercise with exercisers reporting more frequent food cravings for chocolate and fruits and greater difficulty to resist eating compared to non-exercisers ($p<0.05$). Longitudinal analyses revealed significant interaction effects for other exercise ($p<0.05$) with favorable results in men but not women. Furthermore, significant main effects were observed for aerobic exercise, resistance exercise and total exercise with an increase in exercise being associated with a reduced difficulty to resist food cravings ($p<0.05$).

Discussion. The association between exercise participation and hedonic appetite sensations varies by exercise type and sex. Even though exercise was associated with more frequent and greater difficulty to food cravings in the cross-sectional analyses, which may be attributed to greater energy demands, longitudinal results indicate beneficial effects of increased exercise on appetite control, particularly in men.

Keywords: hedonic appetite, physical activity, strength training, endurance training

27 INTRODUCTION

28 Physical activity (PA) and exercise participation are associated with a range of health
29 benefits including reduced risk of cardiovascular disease, diabetes, several cancers and all-
30 cause mortality (Fishman et al., 2016; Warburton, Nicol, & Bredin, 2006). However, clinical
31 exercise trials in overweight and obese individuals frequently report lower-than-expected
32 weight loss, and there remain questions regarding the independent role of exercise in weight
33 management (Dhurandhar et al., 2015; Shaw, Gennat, O'Rourke, & Del Mar, 2006). Various
34 compensatory behaviors, such as reduced non-exercise physical activity and increased energy
35 intake, have been suggested as possible causes of the diminished effect of exercise in weight
36 loss interventions (Dhurandhar et al., 2015; Drenowatz, 2015; N. A. King et al., 2007;
37 Melanson, Keadle, Donnelly, Braun, & King, 2013). Additionally, alterations in food cravings
38 in response to exercise participation also may play an important role regarding adaptations in
39 energy intake.

40 The term food cravings refers to components of the hedonic appetite control system
41 defined as "*a strong urge to eat a particular type of food*" (Graham Finlayson & Dalton,
42 2012; Hill, Weaver, & Blundell, 1991). Although food cravings comprise a natural part of
43 human eating behavior that are reported in 52-97% of individuals studied (Gendall, Sullivan,
44 Joyce, Fear, & Bulik, 1997; Gilhooly et al., 2007; Weingarten & Elston, 1991), they have
45 been suggested to play a central role in the development of obesity. Specifically, food
46 cravings may precede unhealthy eating behavior leading to overeating (G. Finlayson, Arlotti,
47 Dalton, King, & Blundell, 2011; Hill, 2007), as craved foods are often energy dense, with
48 higher fat and lower fiber and protein content than the habitual diet (Chao, Grilo, White, &
49 Sinha, 2014; Gilhooly et al., 2007). Accordingly, food cravings, especially cravings for high-
50 fat foods, have been reported to be associated with higher body mass index (BMI) (Chao et
51 al., 2014; Franken & Muris, 2005; White, Whisenhunt, Williamson, Greenway, & Netemeyer,

52 2002). Further, the frequency of giving in to food cravings is inversely associated with
53 success in energy-restricting weight loss programs (Gilhooly et al., 2007).

54 Enhanced hedonic responses after one session of aerobic exercise have been shown to
55 predict the degree of compensatory energy intake (G. Finlayson, Bryant, Blundell, & King,
56 2009) and to diminish the amount of fat loss after an exercise intervention (G. Finlayson,
57 Caudwell, et al., 2011). Research on the association between exercise and hedonic processes
58 involved in the regulation of eating behavior so far, however, has been inconclusive. An acute
59 bout of aerobic exercise has been shown to increase food cravings in normal weight women
60 (N. A. King, Snell, Smith, & Blundell, 1996) while it was associated with a decrease in the
61 preference for high-fat foods in a mixed sample (McNeil, Cadieux, Finlayson, Blundell, &
62 Doucet, 2015). Besides potential sex differences, McNeil et al. (2015) further showed
63 differential effects of exercise type, as particularly resistance exercise was associated with a
64 decrease in “liking” of high fat food. Habitual chronic exercise participation was also
65 associated with lower food cravings (Horner, Finlayson, Byrne, & King, 2016), while a 6-
66 months exercise intervention did not show any changes in appetite measures (Cornier,
67 Melanson, Salzberg, Bechtell, & Tregellas, 2012). Given the importance of hedonic
68 components of appetite in the regulation of eating behavior (Berthoud, 2006; Graham
69 Finlayson & Dalton, 2012), the possible interaction between exercise and food hedonics
70 requires further investigation as it may have implications for our understanding of the role of
71 exercise as a strategy for weight control (N. A. King et al., 2012).

72 Until now, the majority of research has examined food hedonics after superimposing
73 one single bout of exercise (G. Finlayson et al., 2009; N. A. King et al., 1996; Lluch, King, &
74 Blundell, 1998; Martins et al., 2015; McNeil et al., 2015). Acute effects of exercise, however,
75 might not be indicative of the long-term interaction in a real-world setting, and the relation
76 between habitual exercise and hedonic aspects of appetite remains to be determined. It also

77 should be considered that various exercise modalities might influence food cravings
78 differently (McNeil et al., 2015). The purpose of the present study, therefore, was to explore
79 the associations between participation in different self-selected exercise types and food
80 cravings in young adults.

81

82 **METHODS**

83 *Study Design.* The present analyses include baseline through one-year follow-up data
84 from a large observational study examining the determinants of energy balance. The extensive
85 methodology of the Energy Balance Study has been published previously (Hand et al., 2013).
86 Briefly, 430 (49.3% male, 27.7 ± 3.8 yrs.) healthy adults with a BMI between 20 and 35
87 $\text{kg}\cdot\text{m}^{-2}$ were enrolled. Potential participants were allowed to engage in various recreational
88 exercise regimen but were not involved in competitive sports. Individuals with major acute or
89 chronic conditions and those reporting large changes in their health behavior within the
90 previous 3 months were excluded. Additional exclusion criteria relevant for women included
91 pregnancy within the previous 12 months, planning to become pregnant or planning to change
92 their contraception use during the study. The study protocol was approved by the University
93 of South Carolina Institutional Review Board and was conducted in accordance with the
94 Declaration of Helsinki (World Medical Association, 2001). All participants signed informed
95 consent prior to data collection.

96 *Anthropometrics and body composition.* Trained technicians obtained measurements
97 every three months using standard laboratory procedures with participants in surgical scrubs
98 after an overnight fast. Height was measured to the nearest 0.1 cm using a wall-mounted
99 stadiometer (Model S100, Ayrton Corp., Prior Lake, MN, USA). Body weight was measured
100 to the nearest 0.1 kg using an electronic scale (Healthometer[®] model 500KL, McCook, IL,
101 USA). BMI ($\text{kg}\cdot\text{m}^{-2}$) was calculated using the average of the 3 weight and height

102 measurements. Fat free mass (FFM, kg) and fat mass (FM, kg) were measured by dual energy
103 x-ray absorptiometry (DXA Lunar model 8743; GE Healthcare, Waukesha, WI) and fat mass
104 percentage (%FM) was calculated ($\%FM = [FM / \text{body weight}] * 100$). Change in body
105 composition was calculated as the individual slope across the 5 measurement times.

106 *Exercise participation and physical activity.* Habitual engagement in different exercise
107 modalities was obtained through self-report every three months. As part of a larger
108 questionnaire participants reported average frequency ($d \cdot wk^{-1}$) and time (minutes per session)
109 for various aerobic exercises (running, cycling, swimming and other water-based activities),
110 resistance exercises (upper and lower body resistance exercise), other exercises (sports, group
111 exercise, other structured forms of PA) as well as brisk walking during the previous three
112 months. In order to minimize the risk of reporting incidental PA as exercise, only exercise
113 sessions lasting at least 30 minutes for individual exercise types were included in the
114 calculation of exercise time for each modality and total exercise time ($min \cdot wk^{-1}$). For the
115 cross-sectional analyses participants were stratified as exercisers or non-exercisers based on
116 their participation in each specific exercise type. It was, therefore, possible for individuals to
117 be considered exercisers in more than one exercise category. Change in participation in
118 various exercise types throughout the one-year observation period was used to stratify
119 participants in the longitudinal analyses. Specifically, participants were stratified into never
120 exercise, decrease exercise participation (decline ≥ 15 min/week), maintain exercise (change
121 in exercise < 15 min/week) or increase exercise participation (increase ≥ 15 min/week), based
122 on individual regression slopes across the 5 time points. For change in total exercise a
123 cutpoint of 30 min/week was used to differentiate between increase, maintain or decrease
124 exercise.

125 In addition to subjective reported exercise behavior, participants wore the SenseWear[®]
126 Mini armband (BodyMedia Inc., Pittsburgh, PA) for 10 days at each measurement time point.

127 Compliance was defined as seven days (including 2 weekend days) with at least 21 hours/day
128 verifiable wear time. Using tri-axial accelerometry along with measurements of skin
129 temperature, near body temperature, heat flux and galvanic skin response the armband has
130 been shown to provide accurate estimates of energy expenditure and PA in free-living adults
131 (Johannsen et al., 2010; St-Onge, Mignault, Allison, & Rabasa-Lhoret, 2007; Welk, McClain,
132 Eisenmann, & Wickel, 2007). Using SenseWear's proprietary algorithm (version 7.0
133 professional) average daily time spent sedentary, excluding sleep, in light PA ($1.5 \text{ METs} \leq$
134 $\text{LPA} < 3 \text{ METs}$) and total moderate-to-vigorous PA ($3 \text{ METs} \leq \text{MVPA}$). In addition, time
135 spent in at least 10 consecutive minutes of MVPA (MVPA bout) was determined as current
136 PA recommendations specify that aerobic PA should be performed in episodes of at least 10
137 minutes (Haskell et al., 2007). Weekly time spent in MVPA bout was subsequently used to
138 classify participants as meeting or not meeting current exercise recommendations of at least
139 150 minutes of MVPA per week. In order to be included in the longitudinal analyses valid
140 data during at least three measurement time points, including baseline and one-year follow-
141 up, needed to be available.

142 *Food cravings.* Food cravings were assessed via the Control of Eating Questionnaire
143 (CoEQ) at baseline and one-year follow-up, which is a widely used and validated tool for
144 measuring food cravings (Dalton, Hollingworth, Blundell, & Finlayson, 2015; Greenway et
145 al., 2010; Hill et al., 1991; Wilcox et al., 2010). The CoEQ consists of 21 visual analog scales
146 (VAS) of 100-mm and is designed to assess several features including the desire to eat
147 different types of food, food cravings and the ability to resist urges to eat during the previous
148 7 days. Aspects relevant for the present study included frequency and strength of food
149 cravings for specific foods, as well as difficulty in resisting food cravings and difficulty to
150 control eating. Change in food cravings was calculated as 12-months follow up minus
151 baseline.

152 *Social desirability and social approval.* Participants also completed the Marlow-
153 Crowne Social Desirability Scale (Crowne & Marlowe, 1960) and the Martin-Larsen
154 Approval Motivation Scale (Larsen, Martin, Ettinger, & Nelson, 1976) at baseline and one-
155 year follow-up as social desirability and social approval have been shown to affect self-
156 reported information.

157 *Statistical analyses.* Data for the total sample, and separately for men and women,
158 were subjected to descriptive analyses, which included assessing for normality, skewness and
159 kurtosis of distribution. Differences between men and women were analyzed via ANOVA for
160 continuous variables and Chi square for nominal variables. MANCOVA, initially adjusting
161 for FFM, social desirability and social approval, was used to examine the association between
162 exercise participation, sex (men/women) and food cravings. A second model included
163 objectively determined time spent in MVPA as additional covariate. For the longitudinal
164 analyses MANCOVA, adjusting for change in FFM, social desirability, social approval and
165 baseline exercise time was used to examine the association between change in exercise
166 participation, sex and change in food cravings. Similar to the cross-sectional analyses change
167 in MVPA was used as an additional covariate in a second longitudinal analysis. All statistical
168 analyses were performed using software program SPSS[®] version 22.0 (SPSS Statistics for
169 Windows, Armonk, NY: IBM Corp.) with the level of significance set as $p < 0.05$ and
170 Bonferroni adjustment for multiple comparisons.

171

172 **RESULTS**

173 Cross-sectional analyses. A total of 417 subjects (49% male) provided complete and
174 valid baseline data. The participants were predominantly European American (66.9%) with
175 the majority (83.9%) having a college degree. The prevalence of overweight/obesity was
176 46.3%. Descriptive statistics for baseline characteristics of the total sample and separately for

177 men and women are shown in Table 1. Despite significant differences in body composition
 178 there were no sex differences in BMI and weight status ($p>0.27$). Objectively determined time
 179 spent sedentary during waking hours did not differ between men and women ($p=0.49$) but
 180 women spent more time in LPA ($p<0.01$) while men spent more time in total MVPA and
 181 MVPA bouts ($p<0.01$). Accordingly, men were more likely to meet current PA
 182 recommendations compared to women (82% vs. 59%, $p<0.01$).

	Total Sample (N = 417)	Male Only (N = 204)	Female Only (N = 213)
Age (years)	27.7 ± 3.8	27.4 ± 3.9	27.9 ± 3.7
Height (cm) **	171.6 ± 9.5	178.4 ± 7.1	165.1 ± 6.5
Weight (kg) **	74.8 ± 13.7	80.8 ± 12.2	69.1 ± 12.7
BMI (kg/m ²)	25.3 ± 3.8	25.4 ± 3.2	25.3 ± 4.3
Fat Mass (kg) **	21.4 ± 8.5	18.5 ± 7.7	24.1 ± 8.3
Fat Free Mass (kg) **	54.1 ± 11.3	62.9 ± 8.2	45.7 ± 6.3
% Body Fat **	28.3 ± 9.0	22.4 ± 7.1	34.0 ± 6.7
Sedentary (min/day) ¹	681.7 ± 93.8	685.0 ± 97.8	678.6 ± 89.9
Light PA (min/day) **	216.0 ± 58.5	195.6 ± 50.6	235.6 ± 59.0
MVPA (min/day) **	136.6 ± 77.5	160.0 ± 81.5	112.3 ± 65.6
MVPA bout (min/day) **	54.5 ± 48.3	69.1 ± 51.5	40.5 ± 40.5

183 **Table 1:** Descriptive Characteristics at baseline for the total sample and separately for men
 184 and women. Values are Mean ± SD.

185 ** $p < 0.01$ ¹ excluding sleep

186 PA... physical activity

187 MVPA... moderate-to-vigorous PA

188 MVPA bout... time spent in at least 10 consecutive minutes in MVPA

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The majority of participants (82.3%) reported some form of exercise with no significant difference in participation rates for specific exercise types between men and women, except for walking (Table 2). Total exercise time in those reporting exercise, however, was higher in men compared to women, which was attributed to men spending significantly more time with resistance exercise and other exercise compared to women ($p<0.01$). There were no differences between men and women for time spent with aerobic exercise.

	Total Sample	Male Only	Female Only
Walking (% , min/wk)	67.1 * 108.0 ± 123.0	60.8 113.2 ± 146.4	73.2 103.8 ± 101.0
Aerobic EX (% , min/wk)	49.2 141.9 ± 126.4	52.0 154.4 ± 135.2	46.5 128.6 ± 115.3
Resist. EX (% , min/wk)	53.2 155.0 ± 114.0 **	54.9 192.6 ± 126.5	51.6 116.7 ± 84.4
Other EX (% , min/wk)	55.9 162.0 ± 130.4 **	52.5 189.1 ± 149.8	59.2 139.0 ± 106.6
Total EX (% , min/wk)	82.3 295.2 ± 234.9 **	82.4 346.3 ± 252.3	82.2 246.2 ± 206.1

197

Table 2: Participation rate (%) and time spent in different exercise types for those reporting

198

exercise participation at baseline. Values are percentage of participants reporting

199

exercise and mean ± SD for exercise time.

200

* sig. difference between men and women ($p<0.05$)

201

** sig. difference between men and women ($p<0.01$)

202

203 *Objectively determined PA and food cravings.* Using data from the armband, there
 204 were no sex-by-meeting PA recommendation interaction effects on food cravings. Further, no
 205 main effects of sex or meeting PA recommendations were observed for control of eating.
 206 Women, however, reported more frequent cravings for chocolate and other sweet foods
 207 compared to men ($p \leq 0.05$). They also displayed a greater difficulty to resist food cravings and
 208 were more likely to eat in response to food cravings compared men ($p \leq 0.01$) (Table 3).
 209 Meeting PA recommendations was associated with less frequent cravings for savory foods
 210 ($p < 0.01$), while no main effects were observed for frequency and strength of other food
 211 cravings.

	Total Sample	Male Only	Female Only
Frequency of FC	50.5 ± 21.5	49.5 ± 21.2	51.5 ± 21.7
Strength of FC	51.3 ± 23.4	50.1 ± 22.9	52.3 ± 23.8
Difficulty to resist FC **	43.8 ± 24.5	40.1 ± 23.7	47.3 ± 24.9
Eaten in response to FC	48.2 ± 23.8	47.3 ± 23.5	49.0 ± 24.1
Frequency FC for chocolate **	39.3 ± 28.0	32.0 ± 25.0	46.2 ± 29.0
Frequency FC for other sweet foods *	42.0 ± 26.8	38.7 ± 25.2	45.2 ± 27.9
Frequency FC for fruits	46.4 ± 27.4	46.7 ± 27.6	46.2 ± 27.3
Frequency FC for savory foods	49.6 ± 25.7	50.0 ± 25.8	49.2 ± 25.7
Difficulty to resist eating **	48.5 ± 27.5	42.9 ± 27.0	53.9 ± 27.0
Difficulty to control eating	56.3 ± 18.7	54.6 ± 17.7	58.0 ± 19.6

212 **Table 3:** Self-reported hedonic appetite sensations (range between 0 and 100) for the total
 213 sample and separately for men and women. Values are mean ± SD.

214 FC... Food Cravings

215 * sig. difference between men and women ($p < 0.05$)

216 ** sig. difference between men and women ($p < 0.01$)

217

218 *Self-reported exercise and food cravings.* Similar to total objective PA, there were no
219 interaction effects between self-reported exercise participation and sex on control of eating.
220 There also were no interaction effects on frequency and strength of food cravings for specific
221 foods for self-reported total exercise, walking, aerobic exercise and other exercise. Significant
222 interaction effects, however, occurred with resistance exercise on cravings for fruits, eaten in
223 response to food cravings and difficulty to resist eating ($p<0.05$); men reporting resistance
224 exercise displayed lower cravings for fruits, were less likely to eat in response to food
225 cravings and had less difficulty to resist eating compared to non-exercising men. In women,
226 on the other hand, participation in resistance exercise was associated with increased cravings
227 for fruits, a greater likelihood to eat in response to food cravings and a greater difficulty to
228 resist eating.

229 Significant main effects for self-reported exercise participation on food cravings were
230 observed for walking and aerobic exercise but not for total exercise, resistance exercise and
231 other exercise. Specifically, walking was associated with more frequent cravings for
232 chocolate ($p<0.05$). Aerobic exercise was associated more frequent cravings for fruits and
233 greater difficulty to resist eating in response to food cravings ($p<0.05$) (Figure 1). Results
234 remained essentially unchanged after additionally adjusting for objectively measured time
235 spent in MVPA bouts, except for main effects of aerobic exercise on frequency for cravings
236 for fruits and difficulty to resist eating in response to food cravings, which only remained
237 borderline significant ($p=0.07$).

238

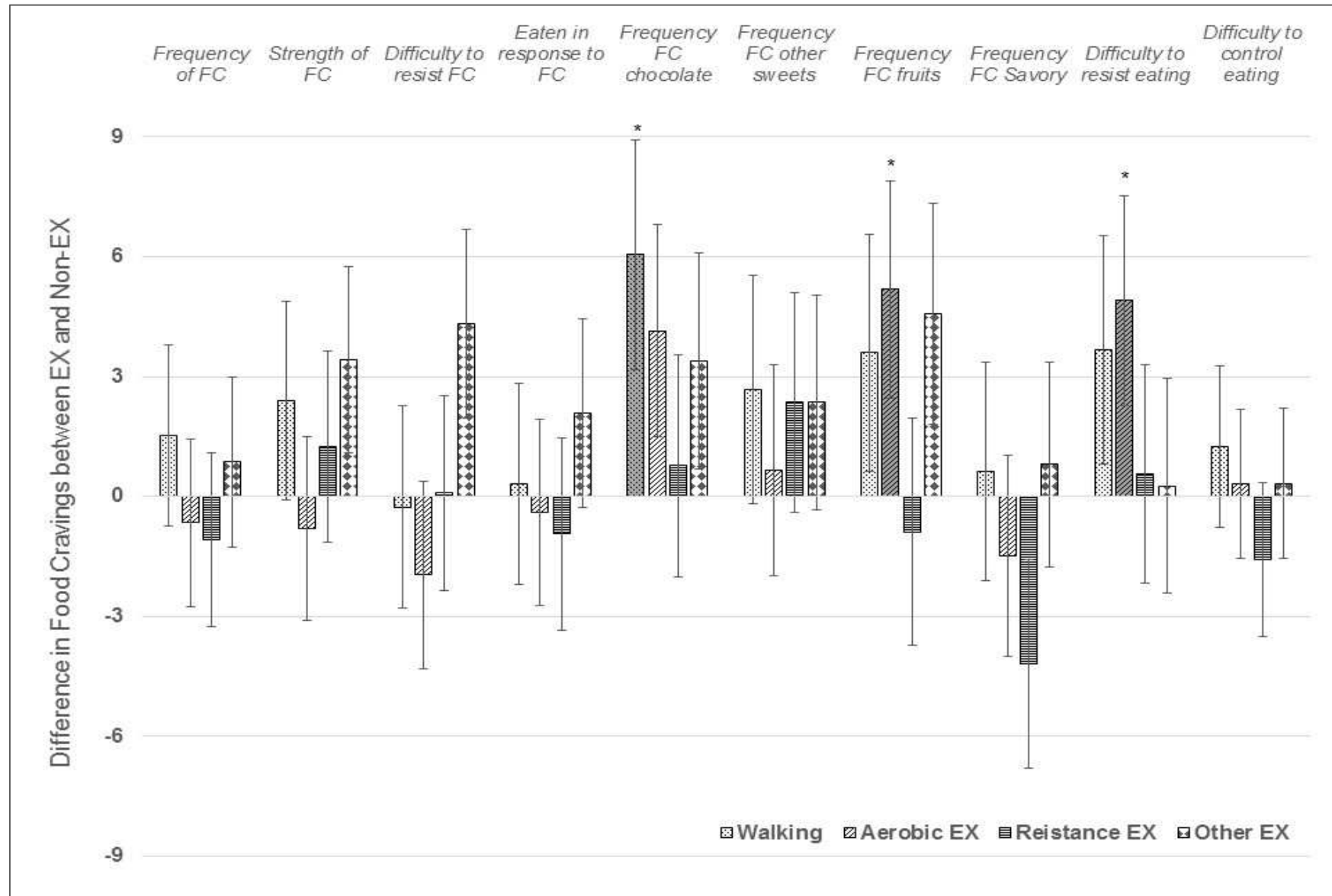


Figure 1: Difference in food cravings (FC) between exercisers and non-exercisers by exercise type. Values are Mean Differences calculated as $FC_{\text{Exercisers}} - FC_{\text{Non-Exercisers}}$, adjusted for fat free mass, social approval and social desirability with S.E.

* $p < 0.05$

EX... exercise

FC...

food

cravings

200 Longitudinal Analyses. A total of 258 participants (52% male) provided valid data for
201 the longitudinal analyses. Except for a higher prevalence of participants with a College degree
202 in those providing longitudinal data ($p < 0.01$), there were no differences in descriptive
203 characteristics and exercise participation at baseline between those included in the
204 longitudinal analyses and those excluded due to missing follow-up data. Over the 1-year
205 period participants experienced a significant weight gain of 1.0 ± 3.6 kg ($p < 0.01$), which was
206 attributed to a significant gain of 0.9 ± 3.0 kg in FM ($p < 0.01$) while FFM remained stable
207 ($\Delta_{\text{FFM}} = 0.1 \pm 1.6$ kg; $p = 0.46$).

208 *Change in self-reported exercise and change in food cravings.* Self-reported exercise
209 time decreased significantly across the entire sample ($\Delta_{\text{Aerobic}} = -10.9 \pm 33.9$ min/week,
210 $\Delta_{\text{Resistance}} = -9.1 \pm 30.3$ min/week, $\Delta_{\text{Other}} = -18.3 \pm 48.5$ min/week; $p < 0.01$). There was no
211 difference in change in exercise participation and food cravings between men and women. No
212 interaction effects for change in exercise participation and sex were observed for control of
213 eating, frequency and strength of food cravings, except for change in other exercise on
214 difficulty to resist food cravings ($p < 0.05$). Specifically, an increase in other exercise was
215 associated with a reduced difficulty to resist eating in men, while there was a non-significant
216 increase in women.

217

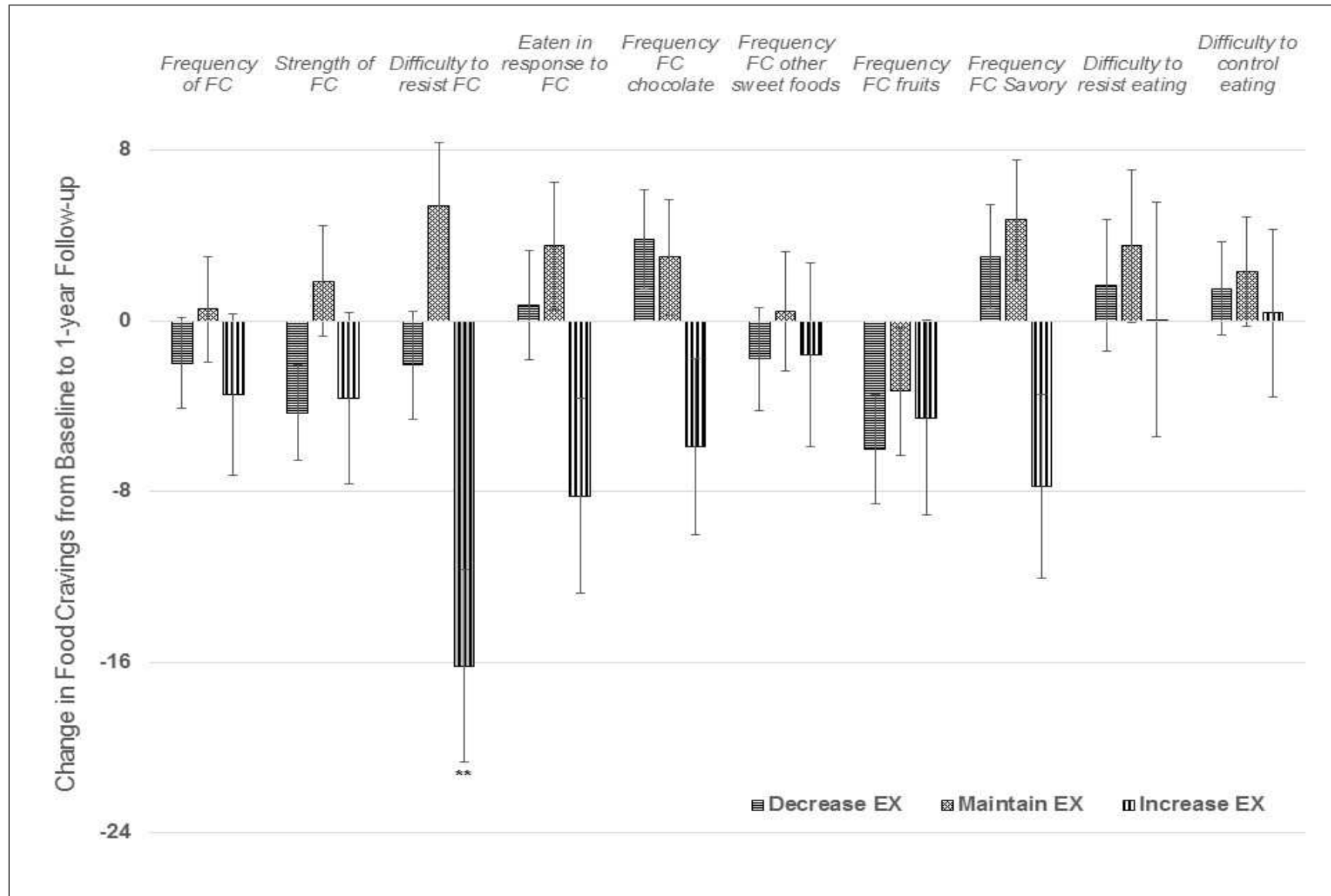


Figure 2: Change in food cravings ($\Delta_{FC} = FC_{12M} - FC_{BL}$) by change in total exercise participation. Values are means adjusted for sex, change in fat free mass, social desirability, social approval and baseline exercise time with S.E.

** $p < 0.01$ * $p < 0.05$

EX... total exercise

FC... food cravings

224 There were no main effects of sex on change in difficulty to control eating, strength or
225 frequency of food cravings and difficulty to control eating. Significant main effects on change
226 in food cravings, however, were observed for total exercise, aerobic exercise and resistance
227 exercise. An increase in total exercise time was associated with a decline in the difficulty to
228 resist food cravings ($p<0.01$) (Figure 2). A decrease in aerobic exercise was associated with
229 an increase in cravings for sweet foods ($p<0.05$) while an increase in resistance exercise was
230 associated with a reduced likelihood to eat in response to food cravings ($p<0.05$). No
231 significant main effects on change in frequency and strength of food cravings were observed
232 for change in walking or other exercise. As was shown for the cross-sectional analyses, results
233 remained essentially unchanged after additionally controlling for change in MVPA bout.

234

235 **DISCUSSION**

236 Food cravings have been suggested to play an important role in determining total
237 dietary intake or intake of specific foods (J. Blundell, 2011; Hill et al., 1991). The present
238 study sought to explore the association between habitual participation in various types of
239 exercise and food cravings in order to enhance our understanding of the complex interaction
240 between exercise and energy intake. Even though there were few significant results, the
241 available data showed a beneficial association between objectively determined PA and
242 cravings for savory foods. In addition, results indicate that specific exercise types influence
243 frequency and strength of food cravings differently. Participation in aerobic exercise was
244 associated with increased cravings for fruits and increased difficulty to resist food cravings
245 while walking was associated with increased cravings for chocolate. Furthermore,
246 associations between exercise participation and food cravings were more favorable in men
247 compared to women. Particularly, participation in resistance exercise was associated with

248 enhanced control of eating in men but not in women. Longitudinal analyses, on the other
249 hand, indicated beneficial effects of sustained exercise participation on food cravings.

250 Beneficial effects of an active lifestyle on the control of eating have been shown
251 previously (J. Blundell, 2011; Grothe et al., 2013; Horner et al., 2016). Few studies, however,
252 have explored the association between different exercise modalities and hedonic liking and
253 wanting of specific foods beyond the acute effects of aerobic exercise (N. A. King et al.,
254 1996; Lluch et al., 1998; Martins et al., 2015). McNeil et al. (2015) compared the effects of
255 one bout of calorie-matched aerobic and resistance exercise on food reward in men and
256 women, and reported lower relative preference for high-fat versus low-fat food following
257 either exercise session, while a decrease in explicit liking was reported after resistance
258 exercise only. The present study also indicates positive effects of resistance exercise on food
259 cravings in men, but not in women. A possible explanation for these sex differences may be
260 that men reported a greater amount of resistance exercise and potentially engage in higher
261 exercise intensities. It can, therefore, be speculated that there exists a minimum threshold for
262 exercise participation in order to experience beneficial effects of exercise on frequency and
263 strength of food cravings as well as control of eating. At this time there remains, however,
264 limited information on the association between exercise duration and intensity with food
265 cravings.

266 Interestingly, exercise types that predominantly rely on aerobic metabolism were
267 associated with greater difficulty to control eating. King et al. (2011) also showed increased
268 appetite ratings after a 60-minute swimming session. A potential explanation for these
269 findings may be that cravings have been suggested to be conditioned expressions of hunger,
270 which are the result of a particular diet (Gibson & Desmond, 1999; Martin, O'Neil, &
271 Pawlow, 2006). Aerobically trained individuals may consume a carbohydrate-rich diet, in
272 order to meet their increased energy demands and it may be possible that this specific diet

273 composition geared towards meeting nutritional demands modifies hedonic appetite
274 sensations. Due to the greater energy demands of exercisers compared to non-exercisers
275 increased food cravings, however, may not necessarily result in a positive energy balance in
276 this population. In a recent review it was further concluded that self-reported ratings of
277 appetite do not reliably predict total energy intake (Holt et al., 2016). More active individuals,
278 therefore, may be able to adjust their energy intake more accurately to meet energy demands
279 despite an increase in perceived hunger. Additionally, increased food cravings do not always
280 need to have negative implications. In the present study, aerobic exercise was associated with
281 more frequent cravings for fruits. Increased cravings for fruits and vegetables also have been
282 reported in individuals who incorporated a healthier lifestyle as part of a diet and behavior-
283 intervention (Schneider et al., 2016). Further, a transfer effect between habitual exercise level
284 and a healthier diet in free-living individuals has been shown (Jayawardene, Torabi, &
285 Lohrmann, 2016). The results of the longitudinal analyses as well as those for objectively
286 measured total PA support the beneficial effects of PA and exercise on appetite control and
287 ability to achieve energy balance (Beaulieu, Hopkins, Blundell, & Finlayson, 2016; J. E.
288 Blundell, Gibbons, Caudwell, Finlayson, & Hopkins, 2015; Shook et al., 2015).

289 The specific mechanisms by which exercise might influence food cravings were not
290 addressed in this study. Previous research suggested a reduced activity in brain regions related
291 to food reward after acute and chronic aerobic exercise (Cornier et al., 2012; Evero, Hackett,
292 Clark, Phelan, & Hagobian, 2012). However, no association between these objective findings
293 and subjectively reported food cravings has been reported (Cornier et al., 2012). Gastric
294 emptying, which is influenced by exercise, has also been proposed to play an important role
295 in the association between regular physical activity and food reward. Faster gastric emptying,
296 which has been observed in active men (Horner, Byrne, Cleghorn, & King, 2015), was
297 associated with lower liking of foods, particularly high-fat foods. These results may be

298 explained by a reduced homeostatic drive with slower gastric emptying, which could be
299 associated with an increased hedonic motivation to eat (Horner et al., 2016). The rate of
300 gastric emptying has further been associated with changes in gut hormones and dopamine
301 release (de Araujo, Ferreira, Tellez, Ren, & Yeckel, 2012; Meyer-Gerspach et al., 2014),
302 which are linked to food reward within the hypothalamus-pituitary-adrenal axes (Sun et al.,
303 2014). A recent review also emphasizes the bidirectional communication between the nervous
304 system and intestinal functions, including gut microbiota (Carabotti, Scirocco, Maselli, &
305 Severi, 2015). The microbiota has been shown to play a role in the control of oxidative stress
306 and inflammatory responses during and following exercise, which provides an additional link
307 for the influence of on the gut-brain axis and food cravings (Clark & Mach, 2016; Mach &
308 Fuster-Botella, 2016). Such research, however, relied predominantly on aerobic exercise and
309 more research is needed to further explore the association between different exercise types
310 and food cravings along with underlying physiological mechanisms (Pelchat, 1997).

311 The findings of this study also support the previously reported differences in food
312 cravings between men and women, with women reporting greater difficulty to control eating
313 than men (Anton et al., 2012; Hormes, Orloff, & Timko, 2014; Pelchat, 1997; Weingarten &
314 Elston, 1991). Nevertheless, sex-by-exercise participation interactions were limited,
315 potentially as a result of differences in exercise volume. Further, it should be considered that
316 fuel utilization differs between men and women in self-selected aerobic exercise, which may
317 affect food cravings differently. Specifically, women have shown higher fat oxidation rates,
318 while men relied more on carbohydrate oxidation (Dasilva et al., 2011; Horton, Pagliassotti,
319 Hobbs, & Hill, 1998). Among other mechanisms these differences have been attributed to sex
320 differences in circulating hormones during exercise, such as epinephrine, and enzymatic
321 activities (Costill, Fink, Getchell, Ivy, & Witzmann, 1979; Horton et al., 1998), which
322 potentially affect food cravings in order to meet differences in fuel demands. Women also

323 have been shown to relate their food cravings to the menstrual cycle (Hormes et al., 2014;
324 Weingarten & Elston, 1991). Besides the interaction between food cravings and changes in
325 ovarian hormones (i.e. estradiol), alterations in serotonin levels throughout the menstrual
326 cycle have been suggested to increase food cravings in the premenstrual phase (Krishnan,
327 Tryon, Horn, Welch, & Keim, 2016; McVay, Copeland, Newman, & Geiselman, 2012).
328 These results underline the complex interaction of various bodily systems in the regulation of
329 food cravings and emphasize the need for additional research, including clinical trials to
330 enhance our understanding of the role of exercise in weight loss and weight management
331 (Devries, 2016).

332 While the present study provides new insights into the role of exercise in appetite
333 control there are some limitations that should be considered when interpreting the results.
334 Information of food cravings and habitual exercise were obtained via self-report and might be
335 subject to a variety of recall-biases (Dyrstad, Hansen, Holme, & Anderssen, 2014). Food
336 cravings were also assessed only for one week at baseline and one-year follow-up, which does
337 not allow to examine alterations in food cravings associated with fluctuations in exercise
338 participation during the observation period. The exclusion of short bouts of exercise (<30
339 min) could have introduced some misinterpretations and potentially misclassifications of
340 participants into the respective exercise groups. Exercise participation at baseline as well as
341 change in exercise participation, however, was significantly associated with objectively
342 determined MVPA ($p < 0.05$). In addition, social desirability and social approval has been
343 included in the statistical analyses in order to account for possible recall bias. Further, the
344 CoEQ, has been validated and recommended as a measurement tool of food cravings (Dalton,
345 Finlayson, Hill, & Blundell, 2015). Generalizability of the present findings may be limited as
346 the majority of participants were European Americans with a college degree and the
347 prevalence of overweight and obesity in the study population was lower than previously

348 reported in a representative sample of young American adults (Ogden, Carroll, Kit, & Flegal,
349 2014). Moreover, total physical activity and, most likely, exercise participation was higher
350 than the average population (Tucker, Welk, & Beyler, 2011). The utilization of longitudinal
351 data over a 12-month period in a free-living population, on the other hand, is a strength as it
352 allows for an examination of the effects of change in exercise participation on food cravings.
353 Further, relying on observational data more accurately represents a real-life situation and self-
354 selected exercise may result in less conscious compensatory behaviors, such as increased
355 energy intake. Given the fact that individuals in prescribed exercise programs tend to deviate
356 from the program towards a preferred exercise dose (Ekkekakis & Lind, 2006), these results
357 may also provide better insights into long-term relationships between exercise participation
358 and control of eating.

359 In summary, results from the present study indicate beneficial effects of habitual
360 exercise participation on food cravings, particularly in men. Associations, however, differed
361 by exercise modality, with greater benefits observed for resistance exercise. Aerobic exercise,
362 on the other hand, was associated with higher cravings for certain foods. Due to the higher
363 energy demands of these activities, this may not necessarily lead to a positive energy balance
364 and subsequent weight gain. However, it could impair the effects of exercise-based weight
365 loss attempts. Accordingly, targeting food cravings in weight loss interventions has been
366 suggested, particularly in individuals who report higher levels of food cravings at baseline
367 (Buscemi, Rybak, Berlin, Murphy, & Raynor, 2017). Overall, results of this study support the
368 previously reported beneficial effects of exercise participation on control of eating and
369 emphasize the importance of an active lifestyle for long-term weight management.

370

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