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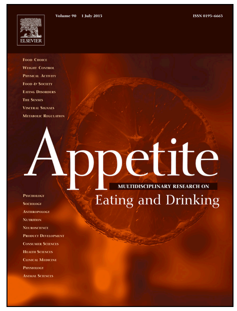

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ABSTRACT

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

INTRODUCTION

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

The term food cravings refers to components of the hedonic appetite control system defined as *"a strong urge to eat a particular type of food"* (Graham Finlayson & Dalton, 2012; Hill, Weaver, & Blundell, 1991). Although food cravings comprise a natural part of human eating behavior that are reported in 52-97% of individuals studied (Gendall, Sullivan, Joyce, Fear, & Bulik, 1997; Gilhooly et al., 2007; Weingarten & Elston, 1991), they have been suggested to play a central role in the development of obesity. Specifically, food cravings may precede unhealthy eating behavior leading to overeating (G. Finlayson, Arlotti, Dalton, King, & Blundell, 2011; Hill, 2007), as craved foods are often energy dense, with higher fat and lower fiber and protein content than the habitual diet (Chao, Grilo, White, & Sinha, 2014; Gilhooly et al., 2007). Accordingly, food cravings, especially cravings for high-fat foods, have been reported to be associated with higher body mass index (BMI) (Chao et al., 2014; Franken & Muris, 2005; White, Whisenhunt, Williamson, Greenway, & Netemeyer, 2002). Further, the frequency of giving in to food cravings is inversely associated with success in energy-restricting weight loss programs (Gilhooly et al., 2007).

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

Until now, the majority of research has examined food hedonics after superimposing one single bout of exercise (G. Finlayson et al., 2009; N. A. King et al., 1996; Lluch, King, & Blundell, 1998; Martins et al., 2015; McNeil et al., 2015). Acute effects of exercise, however, might not be indicative of the long-term interaction in a real-world setting, and the relation between habitual exercise and hedonic aspects of appetite remains to be determined. It also should be considered that various exercise modalities might influence food cravings differently (McNeil et al., 2015). The purpose of the present study, therefore, was to explore the associations between participation in different self-selected exercise types and food cravings in young adults.

METHODS

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

Anthropometrics and body composition. Trained technicians obtained measurements every three months using standard laboratory procedures with participants in surgical scrubs after an overnight fast. Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer (Model S100, Ayrton Corp., Prior Lake, MN, USA). Body weight was measured to the nearest 0.1 kg using an electronic scale (Healthometer® model 500KL, McCook, IL, USA). BMI ($kg \cdot m^{-2}$) was calculated using the average of the 3 weight and height measurements. Fat free mass (FFM, kg) and fat mass (FM, kg) were measured by dual energy x-ray absorptiometry (DXA Lunar model 8743; GE Healthcare, Waukesha, WI) and fat mass percentage (%FM) was calculated (%FM = [FM / body weight] * 100). Change in body composition was calculated as the individual slope across the 5 measurement times.

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

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

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

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

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

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

RESULTS

Cross-sectional analyses. A total of 417 subjects (49% male) provided complete and valid baseline data. The participants were predominantly European American (66.9%) with the majority (83.9%) having a college degree. The prevalence of overweight/obesity was 46.3%. Descriptive statistics for baseline characteristics of the total sample and separately for men and women are shown in Table 1. Despite significant differences in body composition there were no sex differences in BMI and weight status ($p>0.27$). Objectively determined time spent sedentary during waking hours did not differ between men and women ($p=0.49$) but women spent more time in LPA ($p<0.01$) while men spent more time in total MVPA and MVPA bouts ($p<0.01$). Accordingly, men were more likely to meet current PA 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/m²)	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

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

** $p < 0.01$ [1] excluding sleep

PA… physical activity

MVPA… moderate-to-vigorous PA

MVPA bout… time spent in at least 10 consecutive minutes in MVPA

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

Table 2: Participation rate (%) and time spent in different exercise types for those reporting exercise participation at baseline. Values are percentage of participants reporting exercise and mean ± SD for exercise time.

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

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

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

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

FC… Food Cravings

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

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

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

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

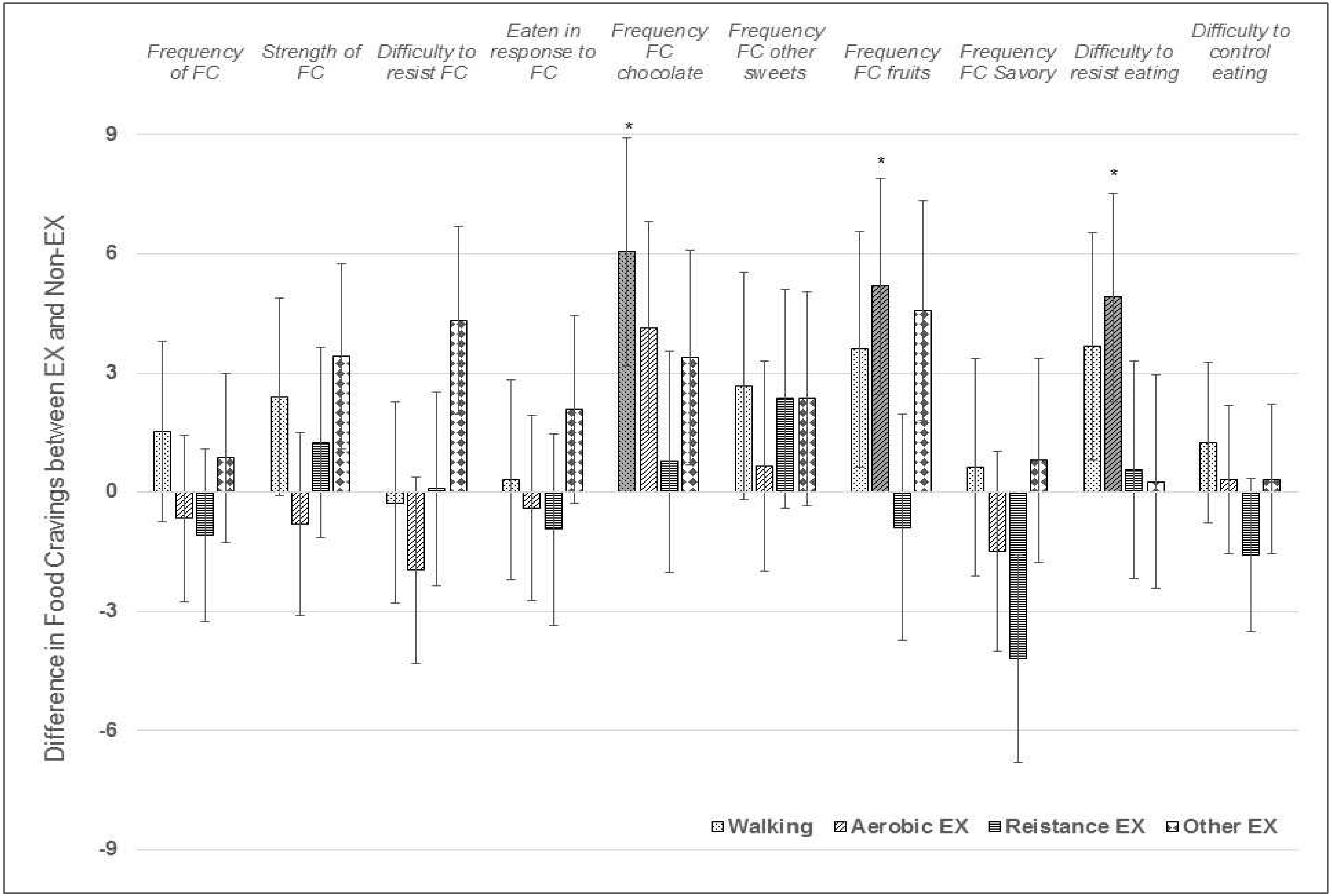

Figure 1: Difference in food cravings (FC) between exercisers and non-exercisers by exercise type. Values are Mean Differences calculated as $FC_{Exercisers} - FC_{Non\text{-}Exercisers}$, adjusted for fat free mass, social approval and social desirability with S.E.

* $p < 0.05$ EX… exercise FC… food cravings

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

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

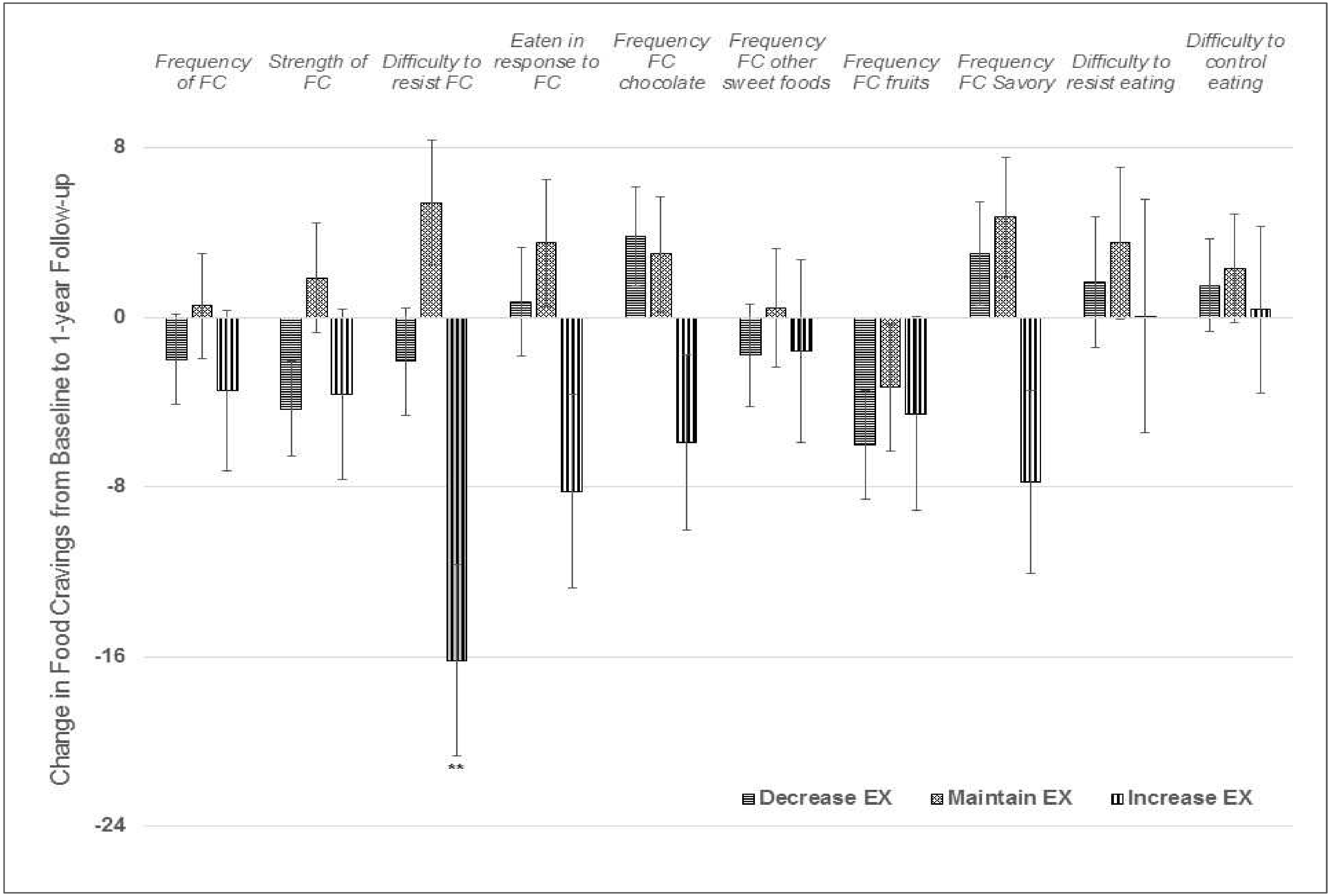

Figure 2: Change in food cravings (Δ_{FC}=FC_{12M} – FC_{BL}) by change in total exercise participation. Values are means adjusted for sex, change in fat free mass, social desirability, social approval and baseline exercise time with S.E.

** $p < 0.01$ * $p < 0.05$ EX… total exercise FC… food cravings

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

DISCUSSION

Food cravings have been suggested to play an important role in determining total dietary intake or intake of specific foods (J. Blundell, 2011; Hill et al., 1991). The present study sought to explore the association between habitual participation in various types of exercise and food cravings in order to enhance our understanding of the complex interaction between exercise and energy intake. Even though there were few significant results, the available data showed a beneficial association between objectively determined PA and cravings for savory foods. In addition, results indicate that specific exercise types influence frequency and strength of food cravings differently. Participation in aerobic exercise was associated with increased cravings for fruits and increased difficulty to resist food cravings while walking was associated with increased cravings for chocolate. Furthermore, associations between exercise participation and food cravings were more favorable in men compared to women. Particularly, participation in resistance exercise was associated with enhanced control of eating in men but not in women. Longitudinal analyses, on the other hand, indicated beneficial effects of sustained exercise participation on food cravings.

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

Interestingly, exercise types that predominantly rely on aerobic metabolism were associated with greater difficulty to control eating. King et al. (2011) also showed increased appetite ratings after a 60-minute swimming session. A potential explanation for these findings may be that cravings have been suggested to be conditioned expressions of hunger, which are the result of a particular diet (Gibson & Desmond, 1999; Martin, O'Neil, & Pawlow, 2006). Aerobically trained individuals may consume a carbohydrate-rich diet, in order to meet their increased energy demands and it may be possible that this specific diet composition geared towards meeting nutritional demands modifies hedonic appetite sensations. Due to the greater energy demands of exercisers compared to non-exercisers increased food cravings, however, may not necessarily result in a positive energy balance in this population. In a recent review it was further concluded that self-reported ratings of appetite do not reliably predict total energy intake (Holt et al., 2016). More active individuals, therefore, may be able to adjust their energy intake more accurately to meet energy demands despite an increase in perceived hunger. Additionally, increased food cravings do not always need to have negative implications. In the present study, aerobic exercise was associated with more frequent cravings for fruits. Increased cravings for fruits and vegetables also have been reported in individuals who incorporated a healthier lifestyle as part of a diet and behavior-intervention (Schneider et al., 2016). Further, a transfer effect between habitual exercise level and a healthier diet in free-living individuals has been shown (Jayawardene, Torabi, & Lohrmann, 2016). The results of the longitudinal analyses as well as those for objectively measured total PA support the beneficial effects of PA and exercise on appetite control and ability to achieve energy balance (Beaulieu, Hopkins, Blundell, & Finlayson, 2016; J. E. Blundell, Gibbons, Caudwell, Finlayson, & Hopkins, 2015; Shook et al., 2015).

The specific mechanisms by which exercise might influence food cravings were not addressed in this study. Previous research suggested a reduced activity in brain regions related to food reward after acute and chronic aerobic exercise (Cornier et al., 2012; Evero, Hackett, Clark, Phelan, & Hagobian, 2012). However, no association between these objective findings and subjectively reported food cravings has been reported (Cornier et al., 2012). Gastric emptying, which is influenced by exercise, has also been proposed to play an important role in the association between regular physical activity and food reward. Faster gastric emptying, which has been observed in active men (Horner, Byrne, Cleghorn, & King, 2015), was associated with lower liking of foods, particularly high-fat foods. These results may be explained by a reduced homeostatic drive with slower gastric emptying, which could be associated with an increased hedonic motivation to eat (Horner et al., 2016). The rate of gastric emptying has further been associated with changes in gut hormones and dopamine release (de Araujo, Ferreira, Tellez, Ren, & Yeckel, 2012; Meyer-Gerspach et al., 2014), which are linked to food reward within the hypothalamus-pituitary-adrenal axes (Sun et al., 2014). A recent review also emphasizes the bidirectional communication between the nervous system and intestinal functions, including gut microbiota (Carabotti, Scirocco, Maselli, & Severi, 2015). The microbiota has been shown to play a role in the control of oxidative stress and inflammatory responses during and following exercise, which provides an additional link for the influence of on the gut-brain axis and food cravings (Clark & Mach, 2016; Mach & Fuster-Botella, 2016). Such research, however, relied predominantly on aerobic exercise and more research is needed to further explore the association between different exercise types and food cravings along with underlying physiological mechanisms (Pelchat, 1997).

The findings of this study also support the previously reported differences in food cravings between men and women, with women reporting greater difficulty to control eating than men (Anton et al., 2012; Hormes, Orloff, & Timko, 2014; Pelchat, 1997; Weingarten & Elston, 1991). Nevertheless, sex-by-exercise participation interactions were limited, potentially as a result of differences in exercise volume. Further, it should be considered that fuel utilization differs between men and women in self-selected aerobic exercise, which may affect food cravings differently. Specifically, women have shown higher fat oxidation rates, while men relied more on carbohydrate oxidation (Dasilva et al., 2011; Horton, Pagliassotti, Hobbs, & Hill, 1998). Among other mechanisms these differences have been attributed to sex differences in circulating hormones during exercise, such as epinephrine, and enzymatic activities (Costill, Fink, Getchell, Ivy, & Witzmann, 1979; Horton et al., 1998), which potentially affect food cravings in order to meet differences in fuel demands. Women also have been shown to relate their food cravings to the menstrual cycle (Hormes et al., 2014; Weingarten & Elston, 1991). Besides the interaction between food cravings and changes in ovarian hormones (i.e. estradiol), alterations in serotonin levels throughout the menstrual cycle have been suggested to increase food cravings in the premenstrual phase (Krishnan, Tryon, Horn, Welch, & Keim, 2016; McVay, Copeland, Newman, & Geiselman, 2012). These results underline the complex interaction of various bodily systems in the regulation of food cravings and emphasize the need for additional research, including clinical trials to enhance our understanding of the role of exercise in weight loss and weight management (Devries, 2016).

While the present study provides new insights into the role of exercise in appetite control there are some limitations that should be considered when interpreting the results. Information of food cravings and habitual exercise were obtained via self-report and might be subject to a variety of recall-biases (Dyrstad, Hansen, Holme, & Anderssen, 2014). Food cravings were also assessed only for one week at baseline and one-year follow-up, which does not allow to examine alterations in food cravings associated with fluctuations in exercise participation during the observation period. The exclusion of short bouts of exercise (<30 min) could have introduced some misinterpretations and potentially misclassifications of participants into the respective exercise groups. Exercise participation at baseline as well as change in exercise participation, however, was significantly associated with objectively determined MVPA ($p < 0.05$). In addition, social desirability and social approval has been included in the statistical analyses in order to account for possible recall bias. Further, the CoEQ, has been validated and recommended as a measurement tool of food cravings (Dalton, Finlayson, Hill, & Blundell, 2015). Generalizability of the present findings may be limited as the majority of participants were European Americans with a college degree and the prevalence of overweight and obesity in the study population was lower than previously reported in a representative sample of young American adults (Ogden, Carroll, Kit, & Flegal, 2014). Moreover, total physical activity and, most likely, exercise participation was higher than the average population (Tucker, Welk, & Beyler, 2011). The utilization of longitudinal data over a 12-month period in a free-living population, on the other hand, is a strength as it allows for an examination of the effects of change in exercise participation on food cravings. Further, relying on observational data more accurately represents a real-life situation and self-selected exercise may result in less conscious compensatory behaviors, such as increased energy intake. Given the fact that individuals in prescribed exercise programs tend to deviate from the program towards a preferred exercise dose (Ekkekakis & Lind, 2006), these results may also provide better insights into long-term relationships between exercise participation and control of eating.

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

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