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ORIGINAL ARTICLE

Associations between average step counts, variability in step counts and nonhomeostatic eating

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Abstract

Purpose Nonhomeostatic drives (e.g., reward and negative emotion) for eating are associated with weight gain over time. Higher average and lower intraindividual variability in physical activity (PA) levels are positively associated with health and weight outcomes, but have not been evaluated in relation to nonhomeostatic eating. The aim of this paper is to examine the associations between PA and nonhomeostatic drives for eating. The hypotheses were that average levels of and consistency in PA would be negatively correlated with nonhomeostatic eating.

Methods Adult participants ($N = 432$) were recruited online and asked to report objectively measured PA using commercially available PA monitors for the previous 7 days and to complete self-report measures of reward-driven and emotional eating.

Results Average daily steps ($M = 6519.36$) were negatively associated with emotional eating, but were not significantly related to reward-driven eating. Intraindividual variability in steps ($M = 2209.85$) was not associated with either type of nonhomeostatic eating. Adjusting for relevant covariates (e.g., age, BMI, gender), average daily step count was negatively associated with emotional eating ($p = 0.01$) but not reward-driven eating ($p = 0.31$) and variability in step counts was positively associated with reward-driven eating ($p = 0.04$) but not emotional eating ($p = 0.52$).

Conclusion The results suggest that greater average levels and lower variability in PA are related to lower nonhomeostatic eating; thus, complex associations between PA and eating exist, and may impact weight and outcomes of treatment related to eating and weight.

Level of evidence V, cross-sectional correlation study.

Keywords Physical activity · Eating behavior · Appetite regulation · Reward-driven eating · Emotional eating · Obesity · Binge eating

Introduction

Engagement in physical activity (PA) is a critical health behavior for all adults [1]. Greater PA is associated with psychological (e.g., improved mood and affect) [2, 3] and physical (e.g., reductions in cardiovascular disease, diabetes, certain types of cancer, and all-cause mortality) [4, 5] health benefits. Although PA-only interventions may induce small changes in weight, PA is associated with improved weight regulation over time and weight loss interventions recommending a combination of reduced energy intake and increased PA produce greater weight losses than reduced energy intake alone [6]. Some research suggests that PA may augment weight losses due to its influence on eating behaviors, rather than simply increasing energy expenditure [7, 8]. It is possible that PA may improve specific eating behaviors, particularly nonhomeostatic eating (i.e., eating when there is no physiological need for energy). Two types of nonhomeostatic eating have been highlighted as high priority for research [9] that might be influenced by PA: reward-driven eating and eating in response to negative emotion (i.e., emotional eating).

Reward-driven eating is defined as eating to obtain the pleasure associated with consuming highly palatable foods rather than for caloric need. Individuals with greater levels of reward-driven eating report lower reported levels of satiation and higher preoccupation with food and loss-of-control over

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eating. Reward-driven eating is associated with weight gain over time and increased risk of obesity [10, 11]. Although understudied, PA may decrease reward-driven eating via two parallel processes. First, PA may address physiologic contributors to reward-driven eating (e.g., improved regulation of appetitive systems and associated feelings of satiation) [12]. Second, PA may address psychologically-driven eating behaviors by improving top-down regulatory control over behavior [13, 14], For example, PA is associated with lower frequency of loss-of-control eating episodes among individuals with binge-eating disorder and bulimia nervosa [15–17], perhaps due to improved inhibitory control related to increased PA.

Emotional eating is defined by eating in response to affective experiences. While eating in response to positive emotions (e.g., joy during a celebration) can be maladaptive, emotional eating is often reported as occurring in response to negative moods and can therefore be conceptualized as a self-soothing or coping strategy [18]. As with reward-driven eating, emotional eating is associated with weight gain [19, 20] and poorer outcomes from weight-loss interventions [21]. PA helps to increase positive affect [2, 3] and may reduce future negative affect [22–24]. Thus, PA may either reduce the intensity of affective experiences that drive emotional eating or reduce eating in response to negative affect. Moreover, emerging evidence suggests that not only the average level of PA, but day-to-day consistency in PA engagement may independently aid in affect regulation [25]; however, research has not evaluated the association of PA variability and nonhomeostatic eating behaviors.

Despite strong theoretical and clinical links, very little research has evaluated the association between average level of PA and reward-driven or emotional eating, and no research has evaluated the association of intraindividual variability in PA and reward-driven or emotional eating. The present study aimed to evaluate the associations between PA and nonhomeostatic eating behaviors (reward-driven and emotional). Associations and independent effects of average engagement in PA and variability in PA were evaluated. It was hypothesized that greater average level of and lower variability in PA would be associated with lower nonhomeostatic eating.

Methods

Adult participants ($N = 432$) were recruited from Mechanical Turk, an online recruitment platform that yields high-quality convenience samples. This service has previously been shown to yield reliable and valid data that is highly generalizable [26, 27] and has been widely utilized across many fields, including in studies of weight and eating [28, 29]. Participants responded to an advertisement for a survey study on PA, eating and weight, were at least 21 years old, spoke English, lived in the United States, and used a commercial activity tracker regularly (e.g., Fitbit, Garmin, pedometer). Consistent with the best practices for MTurk data, all participants had to pass three attention validity checks, IP addresses were screened for multiple entries, and participants with infeasibly short survey times were excluded from analyses. In the present study, all participants self-reported step counts for at least 4 of the previous 7 days. The study was reviewed and approved by the Yale School of Medicine Institutional Review Board. Participants had an average age of 34.26 (± 10.47) years and were predominantly female (63.0%; 36.6% male, 0.2% transgender, 0.2% other), White (79.1%; 7.6% Black/African-American, 5.3% Asian/Asian-American) and non-Hispanic/Latino (87.8%).

Measures of eating behavior were selected from the ADOPT framework (psychosocial domain) [9] measures for nonhomeostatic eating. The Reward-based Eating Scale (RED) [11] is a 7-item scale designed to capture the intensity of aspects of reward-driven eating (i.e., preoccupation with food, loss-of-control over eating, and lack of satiety). The RED demonstrates high reliability and validity [11]. In the present study, Cronbach's alpha = 0.90. The Coping Subscale of the Palatable Eating Motives Scale (PEMS coping) [30] is a 4-item scale designed to assess how often and individual eats response to negative emotions. The PEMS also demonstrates high reliability and validity [30, 31]. In the present study, Cronbach's alpha = 0.89.

Physical activity was determined by commercial wearable device (e.g., Fitbit). Participants reported the type of device used and reported step counts for each of the previous 7 days. Most individuals reported using a Fitbit (42.7%), while a smaller proportion reported using another wearable device (such as Garmin, 2.4%, Jawbone, 0.5%, or another brand, 11.1%), a phone app (like GoogleFit or Apple Health, 38.7%) or a simple pedometer (4.7%). Because commercial wearables may vary in the algorithms used to determine intensity level from raw acceleration data, the present study focused on step counts (rather than minutes of activity at a specified level). Commercial wearable sensors are typically well-validated for measuring step counts [32]. Given that device types may vary from one another, device type was tested as a model covariate. Outcomes were similar in pattern and significance with and without this covariate, so results from models without are presented for ease of interpretability.

Body mass index (BMI) was calculated using participant-reported weight and height. Self-reported measurement of height and weight have been shown to reasonable approximate measured height and weight [33].

Statistical analyses

Individuals who reported step counts that were extreme outliers (determined by box-and-whisker plots; cases with average daily steps > 16,000 steps) were excluded from the present analyses ($N = 8$; 2% of cases). Although these values may have been accurate, they represent an extremely high level of PA as compared to the US population and to the remaining sample.

Descriptive statistics characterized the study sample. Assumptions of normality were tested and met for all models. Correlations examined associations between variables of interest (PA and measures of nonhomeostatic eating) and continuous demographic variables. *T* tests examined mean differences in PA and eating variables by dichotomous demographic variables. Separate regression models were built adjusting for demographic data when the demographic characteristic had a significant association with the eating variable. Each model tested the average daily step counts reported by participants and the variability (conceptualized as the within-person standard deviation of step counts over the 7 days) in step counts as predictors of nonhomeostatic eating (reward-driven or emotional). Although there is conceptual overlap between the nonhomeostatic eating constructs of interest, these were analyzed separately to establish an initial understanding of the associations between PA and different types of nonhomeostatic eating.

Results

Table 1 summarizes associations of demographic characteristics with the study's clinical measures. The age was significantly associated with nonhomeostatic eating such that younger individuals endorsed greater reward-driven and emotional eating. BMI was positively associated with reward-driven, but not emotional eating. Race (defined as White compared to non-White participants) was not associated with differential reward-driven ($M_{White} = 2.67 \pm 0.98$ vs. 2.54 ± 0.94, respectively; $t(422) = -1.17$, $p = 0.24$) or emotional ($M_{White} = 2.28 \pm 1.05$ vs. 2.34 ± 1.20, respectively; $t(422) = 0.52$, $p = 0.60$) eating. Women had significantly higher emotional eating than men ($M_{Women} = 2.37 \pm 1.12$ vs. 2.16 ± 0.99, respectively; $t(420) = -2.03$, $p = 0.04$), but men and women did not differ significantly on reward-driven eating ($M_{Women} = 2.67 \pm 1.00$ vs. 2.64 ± 0.92, respectively; $t(420) = -0.25$, $p = 0.80$).

Individuals reported an average of 6.81 days (range 4–7) of step counts. Most individuals (87%) recorded a full seven-day period. The results were consistent when including all cases compared to when including only those with full data; thus, the results are presented for the full dataset. At a bivariate level, average daily steps were negatively associated with emotional eating, but were not significantly related to reward-driven eating. Variability in steps was not associated with either type of nonhomeostatic eating at a bivariate level (see Table 1). As summarized in Table 2, adjusting for relevant covariates, average daily step count was negatively associated with emotional eating (but not reward-driven eating) and variability in step counts was positively associated with reward-driven eating (but not emotional eating).

Table 2 Independent associations between average and variability in steps and nonhomeostatic eating

	B	SEb	Test statistic	*p* value
Reward-driven eating				
BMI	0.03	0.01	14.80	< 0.001
Age	− 0.01	0.01	− 6.65	0.01
Average steps	− 0.02	0.02	− 1.04	0.31
Variability in steps	0.06	0.03	4.23	0.04
Emotional eating				
Age	− 0.01	0.002	− 28.59	< 0.001
Sex	0.11	0.04	5.65	0.02
Average steps	− 0.02	0.01	− 6.72	0.01
Variability in steps	− 0.01	0.01	− 0.42	0.52

BMI body mass index

Table 1 Correlations between step counts, eating behaviors, and demographic information

	Mean (SD)	1	2	3	4	5
1. Average steps	6519.36 (3379.49)					
2. Variability in steps	2209.85 (1746.11)	0.43**				
3. Reward-driven eating (range 1–5)	2.65 (0.98)	− 0.02	0.09			
4. Emotional eating (range 1–5)	2.29 (1.08)	− 0.14**	− 0.06	0.53**		
5. BMI (kg/m^2)	27.36 (6.07)	− 0.05	− 0.10*	0.16**	0.07	
6. Age (years)	34.26 (10.47)	0.03	− 0.10*	− 0.11*	− 0.23**	0.16**

BMI body mass index, *SD* standard deviation

Discussion

PA has many psychological and physical health benefits, and the current study presents novel findings that greater average PA and greater PA consistency are associated with lower levels of emotional and reward-driven eating, respectively. These are an important finding because nonhomeostatic eating is associated with weight gain, and PA is associated with long-term weight control, yet the nature of the association of PA and weight control is gravely under-studied. The present study represents the first, to our knowledge, evaluation of associations between objectively measured average PA and PA variability and nonhomeostatic eating behaviors.

The current study highlights the importance of both average level of PA, and also day-to-day variations in PA. Increasingly, variability in PA has been associated with poorer psychosocial and health outcomes, including weight gain over time, independent of the effect of average levels of PA [34]. Although creating consistency in PA may be a critical component of building habitually higher levels of PA [35], the present study suggests that consistency in PA may also be important for improving eating-related correlates of PA. Day-to-day consistency in PA behavior is associated with better psychosocial functioning [25]. This may include improved regulation of reward drives, reducing the experience of reward-driven eating (e.g., by regulating physiological cues for eating, reducing feelings of loss-of-control over eating). However, it is also possible that lower reward-driven eating is associated with better psychological functioning [25], making consistent engagement in healthy behaviors such as PA easier to achieve. Moreover, there may be an underlying characteristic that makes consistency in behavior (e.g., PA, eating) easier for some individuals. The direction and nature of these relationships remains uncertain and further research into the consistency (and inconsistency) of behaviors is critical.

Average PA was inversely related to emotional eating, which converges well with literature suggesting that PA is associated with improved positive affect. It may be that emotional eating is lower among those with greater PA simply because emotional experiences are improved. Again, however, temporal associations were not evaluated in the present study. In addition, eating in response to positive emotions was not evaluated; thus, whether this type of eating may differ in association with PA from eating in response to negative emotions is unknown. Future research should evaluate how these associations may change over time as a result of increasing PA and whether acute engagement in PA reduces emotional eating.

Interestingly, average PA was not associated with reward-driven eating after controlling for consistency in PA and consistency in PA was not associated with emotional eating after controlling for average PA. While there may be clear links between PA and nonhomeostatic eating, these results highlight that this is an emerging area of research that requires additional study. It is possible that the mechanisms through which PA improves emotional eating may differ from those through which PA improves reward-driven eating. Alternatively, it may be that the theoretical overlap and high correlation between nonhomeostatic eating constructs warrants collapsing emotional eating and reward-driven eating into a single construct (i.e., that separating these constructs simply weakens the ability to observe real effects). Better understanding these associations may have important implications for treatments for inactivity and changes in eating behaviors. For instance, evidence-based lifestyle and behavioral weight control programs recommend both changes in eating behaviors and increases in PA to achieve weight loss [36]. Reward-driven and emotional eating may make it difficult for an individual to reduce calories or alter eating behaviors as they experience strong drives to engage in eating even when energy is in balance. It is possible that PA may be especially helpful for individuals who experience these appetitive drives more often, such as those who experience disordered eating marked by reward-drive (e.g., recurrent binge eating in binge-eating disorder).

The present study focused on total PA, rather than specific types of PA or whether PA was characterized by lifestyle activity or intentional bouts of exercise. Prior research has observed that the intensity and duration of exercise may impact hunger levels among some individuals (e.g., [37]). Thus, it is possible that intentional intense or prolonged exercise may have a differential impact on nonhomeostatic eating. Additionally, there may be cognitive links between nonhomeostatic eating and intentional exercise, for example, individuals engaging in greater exercise may also have a greater desire to avoid nonhomeostatic cues or individuals engaging in greater exercise may feel greater need for rewards for having engaged in the healthy behavior. Finally, the present study did not evaluate compulsive exercise separately from total PA; whether compulsive drive for exercise may impact the associations between PA and nonhomeostatic eating is unclear, although some evidence suggests that compulsive exercise is associated with increased disordered eating behavior [38]. Future work should seek to disentangle these complex relationships to better understand the impacts of different types of exercise and activity on nonhomeostatic eating.

Strengths and limitations

Strengths of this present study include measurement and sample size. Measures used in the current study were derived from NIH-recommended measurement of nonhomeostatic eating [9], and measurement of PA was operationalized as step counts, which is easily measured using commercially available wearable devices. While step counts only represent one way to measure PA and do not account for intensity level or other types of activity (e.g., strength training), walking is a widely engaged in activity and provides a proxy measure of overall activity level [39], and report of step counts may be less influenced by the reporting biases inherent in participant recall of the length of time spent at certain levels of perceived intensity. However, step counts were derived from self-report using objective trackers, thus these data represent a mix of objective and self-report data and may retain some of the flaws of self-report. Moreover, all participants were required to both own and use a personal step tracking device, and thus results may not generalize to those who do not (e.g., our sample may be more focused on PA than the general population). Future research can build on this study by measuring different types of PA and using different measurement approaches, such as laboratory assessment or study provided objective measurement devices. The large sample size provided adequate power for observing the associations of interest. However, the sample was predominantly non-Hispanic, White, and female. Collapsing race categories into "White" and "Non-White" precludes observation of differences in these relationships between what are highly distinct racial categories. Future research should evaluate associations of PA and eating behaviors within and across other important groups not well-represented in the current sample, as associations may differ (e.g., due to cultural influences on eating behaviors or beliefs about PA). Additionally, individuals' anthropometric information was self reported and no objective measure of eating was included. Future research should continue to evaluate associations (including directional associations) between PA and specific eating behaviors.

Conclusion

In conclusion, our findings suggest that PA has important relationships with nonhomeostatic eating behaviors. These associations may be especially important when considering the effects of PA within weight control programs, as nonhomeostatic eating may drive weight gain or undermine weight loss efforts. Although the direction of this association cannot be discerned given the cross-sectional nature of the study, this study provides critical initial evidence that highlights the importance of evaluating both average levels of PA and intraindividual variability in PA as they relate to nonhomeostatic eating behaviors. Targeting both average PA and PA variability in behavioral weight control interventions could improve treatment outcomes among individuals engaging in nonhomeostatic eating behaviors. Future clinical research on these associations is essential to improve obesity treatment.

What is already known on this subject?

Nonhomeostatic drives (e.g., reward and emotion) for eating are associated with weight gain over time. Higher average and lower intraindividual variability in physical activity (PA) levels are positively associated with health and weight outcomes but have not been evaluated in relation to nonhomeostatic eating.

What does this study add?

Higher levels of physical activity are associated with reduced non-homeostatic eating. Importantly, different factors (overall average vs. consistency) may relate differentially to different types of nonhomeostatic eating (e.g., emotional eating vs. reward-driven eating). Understanding these pathways may help to improve treatments for eating and weight disorders.

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Declarations

Conflict of interest CMG also reports book royalties from Guilford Press and from Taylor & Francis Publishers outside the submitted work. All other authors declare no potential conflicts of interest.

Ethical approval This study was approved by the Yale University Institutional Review Board.

Informed consent All participants provided informed consent prior to participating.

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