HHS Public Access
Author manuscript
Int J Obes (Lond). Author manuscript; available in PMC 2019 September 05.

Published in final edited form as:
Int J Obes (Lond). 2019 September ; 43(9): 1681–1690. doi:10.1038/s41366-018-0299-3.

The Influence of 15-week Exercise Training on Dietary Patterns among Young Adults

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Abstract

BACKGROUND/OBJECTIVES: Little is currently known about how exercise may influence dietary patterns and/or food preferences. The present study aimed to examine the effect of a 15-week exercise training program on overall dietary patterns among young adults.

SUBJECTS/METHODS: This study consisted of 2680 young adults drawn from the Training Intervention and Genetics of Exercise Response (TIGER) study. Subjects underwent 15 weeks of aerobic exercise training, and exercise duration, intensity, and dose were recorded for each session using computerized heart rate monitors. In total, 4355 dietary observations with 102 food items were collected using a self-administered food frequency questionnaire before and after exercise training (n = 2476 at baseline; n = 1859 at 15 weeks). Dietary patterns were identified using a Bayesian sparse latent factor model. Changes in dietary pattern preferences were evaluated based on the pre/post-training differences in dietary pattern scores, accounting for the effects of gender, race/ethnicity, and BMI.

RESULTS: Within each of the seven dietary patterns identified, most dietary pattern scores were decreased following exercise training, consistent with increased voluntary regulation of food intake. A longer duration of exercise was associated with decreased preferences for the Western (β: −0.0793; 95% credible interval: −0.1568, −0.0017) and Snacking (β: −0.1280; 95% credible interval: −0.1877, −0.0637) patterns, while a higher intensity of exercise was linked to an increased preference for the Prudent pattern (β: 0.0623; 95% credible interval: 0.0159, 0.1111). Consequently, a higher dose of exercise was related to a decreased preference for the Snacking

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Conflict of interest: None declared

Competing Interests None declared.

pattern (β: −0.0023; 95% credible interval: −0.0042, −0.0004) and an increased preference for the Prudent pattern (β: 0.0029; 95% credible interval: 0.0009, 0.0048).

CONCLUSION: The 15-week exercise training appeared to motivate young adults to pursue healthier dietary preferences and to regulate their food intake.

Introduction

The transition from adolescence to young adulthood is associated with a variety of major lifestyle changes that are likely to influence health-related behaviors.[1] Young adults have more independence over their dietary choices, while still being financially limited, which may lead to poor eating habits, and positive energy balance.[2–8] Previous studies have reported that considerable weight gain takes place during the college years, and being mildly to moderately overweight at age 20 to 22 years is associated with increased risk for obesity in later years.[7–11] Thus, it is important to identify an effective intervention strategy targeting this lifecycle transition to prevent weight gain and obesity that may be less malleable in adulthood.

One potential mechanism for improvements in dietary behavior is through exercise.[12,13] The majority of studies that have measured the effect of exercise on dietary behaviors have been focused on appetite,[12–16] with no definitive consensus as to whether exercise promotes or diminishes appetite. Studies have shown inconsistent results regarding whether exercise motivates alterations in macronutrient intake.[15–18] In rodents, wheel running led to a sex-dependent decrease in preference for high fat.[19–24] In humans, physical exercise has been associated with altered dietary preferences for sweet substances, salt, high fat foods, and high energy density foods.[25–31] Considering its role in healthy weight maintenance and weight loss,[32,33] exercise may provide behavioral adaptation to counteract obesity, partly through changes in dietary preference. Understanding the role of exercise in dietary preferences among young adults is important in maintaining lifelong health and designing effective intervention programs.

Though the available evidence supports the potential role of exercise on dietary preferences, most of the research on this topic has focused on isolated categories within a diet or on single nutrients. The primary limitation of this approach is that it may fail to acknowledge the interactive effects of multiple dietary components. When an individual increases or restrains his/her intake of one dietary component, it is often accompanied by changes in other aspects of eating behavior. Given that individuals eat foods and nutrients in a variety of combinations under free-living circumstances, the impact of exercise on dietary preferences may be more complicated than previously described. Accordingly, it is necessary to examine how exercise and its characteristics influence individuals' preferences for overall eating patterns.

A data-driven dietary pattern analysis has been used as a means of characterizing habitual eating patterns. This approach typically assumes that the collection of observed food intakes can be expressed as a small set of underlying patterns in data, in which each pattern is comprised of a multi-faceted composite of dietary consumption that has a natural interpretation as an unobserved dietary characteristic. Importantly, pattern analysis generates a vector of pattern scores that describes how much each dietary pattern contributes to observed dietary intake, allowing for the examination of the transition of dietary preferences quantitatively by evaluating the changes in these scores.

In the present study, we examined the influence of a 15-week exercise training protocol on dietary patterns in young adults with different exercise characteristics including exercise intensity, duration, and dose. Habitual dietary patterns were derived using data from the Training Intervention and Genetics of Exercise Response (TIGER) study, and transitions of dietary pattern preferences following exercise training were evaluated using data-driven dietary pattern analysis. We also examined how gender and race/ethnicity interact with exercise in influencing dietary patterns.

Materials and Methods

Study cohort

The TIGER study is a prospective cohort study with the goal of introducing sedentary young adults to regular exercise via a 15-week, 3 d/wk aerobic exercise training provided in the form of a course for college credit. Between 2003 and 2015, sedentary college students who had exercised less than 30 min/wk without caloric restriction for the 30 days prior to participation were recruited at the University of Houston (2003–2008) and the University of Alabama at Birmingham (2010–2015). Exclusion criteria for study participation included: a physical contraindication to exercise (e.g., cardiomyopathy), pregnancy, and/or a known metabolic disorder that may influence body composition. The study was approved by the Institutional Review Boards of each participating institution, and written informed consent was obtained from all study participants.

Exercise assessments

The prescribed exercise sessions consisted of 30 min aerobic exercise at 65%−85% of age- and gender-specific maximum heart rate reserve, along with a 5-min warm-up and a 5-min cool-down. Exercise classes were offered every hour from 7 am to 2 pm each Monday, Wednesday, and Friday, and subjects were allowed to self-select their optimal workout time. During each exercise session, participants wore computerized heart rate monitors (Polar Inc, Bethpage, NY) that recorded minute-to-minute heart rate, date, time and duration of each exercise session. Prior to the beginning of the 15-week training program, a detailed instructions were provided regarding the use of heart rate monitors and the procedures involved in the TIGER workout sessions, which included a short workout session to ensure monitors were placed correctly for each participant. Heart rate data were downloaded after each session and checked for potential errors. Participants chose from a variety of aerobic exercise modes, including treadmill, elliptical trainer, stair stepper, and/or exercise bike. Participants were permitted to exercise for longer durations (up to 60 min) than the prescribed session. More details on the exercise protocol are available elsewhere.[34,35]

In this study, exercise duration was recorded in minutes, and an average exercise intensity for each session was calculated based on percent of heart rate reserve (%HRR). Total exercise dose was quantified using a heart rate physical activity score (HRPAS) that adjusts exercise duration in minutes by exercise intensity for each session, which were then summed over all workout sessions.[35] Exercise compliance was evaluated by comparing observed values of the HRPAS score to prescribed values, calculated on the basis of a minimum %HRR of 65% for at least 30 min per session, summed over all possible sessions.

Dietary assessments

Dietary intake was assessed via the Block Food Frequency Questionnaire (FFQ, NutritionQuest, Berkeley, CA), providing habitual intakes of 102 food items of study participants. Reliability of the Block food frequency questionnaire has been described previously, and this instrument has been used across multiple studies in the field of nutritional epidemiology.[36] Survey instructions were provided to study participants prior to the 15-week exercise program via an orientation session, and participants completed the surveys in class where any questions or ambiguities could be addressed. Participants were asked to answer how often they consumed each food item using nine frequency categories, ranging from “never” to “every day” at baseline and at 15 weeks. Each food intake was converted to a daily frequency and then was standardized by subtracting its mean and dividing the difference by its standard deviation. In the present analysis, dietary observations were excluded if participants were missing demographic or anthropometric data, had invalid exercise data (e.g., technical errors with the heart rate monitors), and/or had more than 10 missing responses of FFQ food item questions. In total, 4 355 dietary observations (n = 2476 at baseline; n = 1859 at 15 weeks) were available, where 1655 participants had valid dietary observations at both baseline and 15 weeks, 821 participants had an observation only at baseline, and 204 participants had an observation only at 15 weeks for a total of 2680 individuals. This samples included 1730 women and 950 men from diverse racial/ethnic groups, including non-Hispanic white (n = 1145), African-American (n = 784), Hispanic (n = 361), Asian (n = 156), Asian Indian (n = 78), and others (n = 156).

Statistical analysis

Average changes of anthropometric measures and exercise parameters were summarized using means and standard deviations (SD). A Bayesian sparse latent factor model was applied to the baseline dietary data in order to derive habitual dietary patterns. In this model, a factor loading matrix expresses how each dietary pattern is associated with observed food intakes, and factor score (i.e., dietary pattern score) represents an individual’s relative position on a given dietary pattern. In the present study, sparsity constraints enforced via a Bayesian variable selection technique were imposed on factor loadings, providing a posterior inclusion probability for each factor loading.[37] This probability reflects the degree to which model favors the inclusion of a food in each of latent factors, which are central to interpreting dietary patterns. Here, food with posterior inclusion probability > 0.95 (i.e., food relevant to a given dietary pattern with a high probability) were used to define a food subset for each dietary pattern. The influence of gender, race/ethnicity, and BMI were isolated from the assessment of dietary pattern structures by including them as covariates to identify global patterns of all study participants.[38] The number of dietary patterns were determined by retaining all factors that included at least three foods with posterior inclusion probability above the cut-off. The factor loading matrices were assumed to remain unchanged after 15 weeks so that the interpretation of dietary patterns does not changes over time, and dietary pattern scores at different time points are comparable on the same basis. On the other hand, dietary pattern scores are assumed to vary at different time points, allowing the changes of dietary patterns to be captured by score differences before and after the 15-week exercise training. A multivariate linear mixed-effects model was used to estimate factor scores at baseline and at 15 weeks. In this study, the random effects component was used to account for individual-dependent and cohort-dependent variation not captured by the fixed effects component that includes linear predictor, such as gender, race/ ethnicity, and exercise parameters. More details on the model specification for the estimation of dietary patterns scores are available in Supplementary Method.

We first evaluated the general trend of the exercise intervention effect on dietary patterns among all participants, with covariates including gender, race/ethnicity, and BMI. Gender and race/ethnicity were dummy-coded, with male and non-Hispanic white acting as the reference group of each category, respectively. Next, we investigated how the influence of exercise training on dietary pattern preferences varies with different components of exercise characteristics, gender, and race/ethnicity by evaluating their interactions with the time variable. Model parameters were estimated in a Bayesian context by placing prior distributions over those parameters and updating these distributions with the observed data. Inference was based on the posterior distribution via samples obtained from a Markov Chain Monte Carlo method. Model estimates were summarized using their posterior means with 95% credible intervals that represented an interval having a 95% probability of containing the true value of the model parameter. Missing values in food intakes were dealt with using a model-based imputation approach in which missing values were imputed at each iteration of the Markov Chain Monte Carlo sampler. All analyses were performed using the BFRM software[39] and Stan.[40] Figures were generated using the ggplot2 package[41] in R version 3.4.3.[42]

Results

Table 1 shows the descriptive statistics of exercise parameters and anthropometric measurements before and after the 15 weeks of exercise training. Among 2680 participants, 2053 participants were identified as exercise compliant, while 627 participants were classified as non-compliant on the basis of the prescribed exercise dose. Exercise compliance was associated with generally more positive changes in anthropometric measures, compared to non-compliance.[43]

Figure 1 displays seven habitual dietary patterns identified from the TIGER study participants, which were labeled as Prudent, Western, Snacking, Ethnic, Meat and Dairy Alternatives, Alcohol, and Milk and Cereal. Dietary patterns were interpreted based on posterior inclusion probabilities of individual food-factor pairs (Figure 1A) and the factor loading estimates above the probability threshold (Figure 1B). The Prudent pattern was mainly associated with a high frequency intake of fruits, vegetables, and low-fat foods and a low frequency intake of fried foods, and soft drinks. The Western pattern was primarily associated with a high frequency intake of red meat, processed meat, fried foods, soft drinks, breads, and pasta dishes. The Snacking pattern was associated with a high frequency intake of foods such as cookies, sweets, and salty snacks. The Ethnic pattern showed positive associations with foods such as tacos, burritos, tortillas, and salsa. The remaining patterns were designated based on their food subsets.

Figure 2 displays the treatment effects of exercise training on dietary pattern scores. Most dietary patterns scores were decreased or unchanged after the exercise intervention. This trend was confirmed in the analysis performed at the individual food item level in which most of food frequency intakes were decreased at 15 weeks (Supplementary Figure 1). There were insignificant changes in the scores of Meat and Dairy Alternatives and Alcohol patterns between before and after exercise training.

Figure 3 displays how changes in dietary pattern scores vary with different values of exercise duration, intensity, and dose. A longer duration of exercise was associated with a decrease in preferences for foods in the Western (β: −0.0793; 95% credible interval: −0.1568, −0.0017), and Snacking (β: −0.1280; 95% credible interval: −0.1877, −0.0637) patterns and an increase in preference for the Milk and Cereal pattern (β: 0.0700; 95% credible interval: 0.0107, 0.1258) (Figure 3A). A higher intensity of exercise was linked with a greater preference for the Prudent pattern (β: 0.0623; 95% credible interval: 0.0159, 0.1111) (Figure 3B). Accordingly, participants who achieved a higher dose of exercise were more likely to increase their preference for the Prudent pattern (β: 0.0029; 95% credible interval: 0.0009, 0.0048) but reduce the preference for the Snacking pattern (β: −0.0023; 95% credible interval: −0.0042, −0.0004) (Figure 3C). Figure 3D displays the effects of exercise on dietary pattern preferences as a function of exercise compliance. Participants who achieved the prescribed dose of exercise (i.e., compliant), were more likely to maintain their preferences for the Prudent pattern following exercise training, compared to their non-compliant counterparts. In addition, participants who were exercise compliant showed a decrease in the preference for the Snacking pattern, whereas those who were non-compliant exhibited an increased in the Snacking pattern.

Figure 4 displays how the influence of exercise on dietary preference varies by gender or race/ethnicity. In this study, no gender differences were observed in the changes in dietary preferences following exercise training (Figure 4A). In contrast, the race/ethnicity of participants appeared to be associated with different patterns in dietary preferences. Asian participants showed a distinct trend in which the Western pattern score was increased after exercise training (β = 1.9006; 95% credible interval = 0.3093, 3.4390), in contrast to all other racial/ethnic groups which experienced a decrease in the Western pattern following exercise training (Figure 4B). Hispanic participants showed a decreasing trend in the Ethnic pattern score, which was not seen in other racial/ethnic groups (β = −1.0153; 95% credible interval = −1.5565, −0.4775) (Figure 4C). Asian Indians showed a similar trend for the Ethnic pattern score, but with weaker evidence (β = −0.9186; 95% credible interval = −2.0636, 0.1555).

Discussion

In this study, we examined the influence of exercise training on habitual dietary patterns of young adults and its associations with exercise characteristics, including exercise duration, intensity, and dose. To describe overall dietary preferences, we used data-driven dietary patterns identified using a Bayesian sparse latent factor modeling. Seven dietary patterns were identified, including Prudent, Western, Snacking, Ethnic, Meat and Dairy Alternatives, Alcohol, and Milk and Cereal. Each dietary pattern score reflects an individual's relative standing regarding their frequency of making choices on a given dietary pattern. Changes in dietary preferences were evaluated before and after the 15-week exercise training protocol.

The current literature primarily focuses on the role of exercise in contributing to a negative energy balance via increasing energy expenditure, whereas there is still some controversy regarding the role of exercise on food intake.[13,16] At a physiological level, it has been established that exercise can influence appetite-regulating hormones.[44] However, such hormonal changes in response to exercise are not necessarily linked with post-exercise food intake because exercise may influence or be influenced by other behavioral, and environmental factors that are thought to affect their dietary intake. In the present study, most of dietary pattern scores were decreased after exercise training, which was consistent with the overall decreasing trend in intake frequency of a wide array of food items. Although the 15-week exercise training did not result in substantial mean changes in anthropometric measures in the total cohort, the more positive changes in body/size were observed in those were exercise compliant, indicating that engaging in regular exercise may influence participants to regulate food intake as a means of controlling their body shape or improving health.

The influence of exercise training on dietary pattern preferences was dependent on different components of exercise. We observed that a longer duration of exercise provides a motive for restraining dietary preferences in the Snacking and Western patterns, while a higher intensity of exercise induces an increased preference for the Prudent pattern. Although the current analyses linked exercise duration and intensity to different aspects of dietary preferences, the overall trend indicated an increased preference for healthier diets. This tendency was more pronounced in exercise dose where individuals with a higher exercise dose were more likely to prefer the Prudent pattern, while less likely to favor the Snacking pattern. These results support previous findings that exercise motivates individuals to pursue healthier nutritional habits.[45–47] It is important to acknowledge that that there might be people who are vulnerable to failure in self-regulation of food intake. Those individuals may exhibit increased consumption of palatable but unhealthy foods following exercise, on the basis of compensatory health beliefs.[48] Thus, future research should address not only linear relationships between exercise characteristics and dietary responses, but also investigate the optimal level of exercise training that can lead to positive dietary changes, accounting for individual variability in response to exercise. Exercise duration was also linked with the increased preference for the Milk and Cereal pattern, but it was not possible to conclude its clinical implication due to the limited information on types and compositions of cereals that participants consumed.

When transitions of dietary pattern preferences were compared between non-compliant and compliant individuals, those who were non-compliant showed a steeper decrease in the preference for the Prudent pattern and an increased preference for the Snacking pattern. Those who were compliant with the exercise prescription had a more moderate decrease in the preference for the Prudent pattern and a reduced preference for the Snacking pattern following exercise training. For young adults, snack foods are cheap, easy to access (e.g., off-campus grocer, on-campus cafeteria, and vending machines), and easy to store, compared to healthier options, such as fruits and vegetables. Indeed, students may not have the necessary skill set for planning their meals, and the college years have been associated with skipping meals, diminished food variety, and frequent consumption of salty and sugary snacks.[8,49,50] The reduced preference for the Snacking pattern following exercise is parallel with the findings from previous research claiming that exercise may reduce snacking urges.[51–54] Given that a majority of snack foods are high in sugar, sodium, and/or fat and snacking often occurs in the absence of hunger due to external factors such as pleasure, taste, and convenience,[55–57] a reduced urge to eat snack foods following exercise could have a significant impact on health.

Changes in dietary pattern preferences in response to exercise varied by race/ethnicity. Hispanic participants showed a greater decrease in the preference for the Ethnic pattern. As indicated in the Ethnic pattern score at the baseline, this may simply due to their higher habitual consumption of foods belonging to the Ethnic pattern that consist of a group of Hispanic foods. It would have been easier for Hispanic participants to decrease consumption of food that they consumed more frequently. Asian participants exhibited a slight increase in the preference for the Western pattern following exercise training. It is not possible to explicitly identify the underlying mechanism and clinical significance of these observations, justifying more research on this topic. We did not identify a role of gender in influencing post-exercise dietary preferences, unlike previous animal studies that suggest sex-dependent effects on dietary preferences.[22,24]

It is important to consider that, in our data-driven dietary pattern approach, foods that constitute particular dietary patterns and the resulting dietary pattern scores are learned from data, and they can vary from sample to sample. The scores of seven dietary patterns were scaled based on the data from the present study. Consequently, generalization of the exercise influence on patterns of food intake requires replication and confirmation of our results through future studies.

The present study has some limitations. The current analyses relied on the participants' self-report dietary intake, which may be subject to measurement errors. Participants were self-selected, possibly representing those more interested in improving their health behaviors. Our within-subject design did not include a control group; thus, we were not able to confirm if self-reported dietary intake changes over time, independent of exercise training. Voluntary exercise outside the in-class workout sessions was not considered in the present analyses. Subjects reported out-of-class activity via an online tracking system, and on average, in-class exercise comprised the majority of physical activity for the participants (data not shown). Exercise sessions were provided every hour from 7 am to 2 pm, and some studies have suggested that exercise performance could be influenced by the time of day in which exercise is performed.[58–60] Finally, additional follow-up measurements were not collected after the end of study, making it difficult to evaluate whether or not the observed transitions persist. It may be possible that a participant engages in compensatory eating behaviors after the completion of intervention program, nullifying the observed positive trend for health brought on by exercise training.

In conclusion, the results of present study revealed that the15-week exercise training program motivated young adult participants to change their dietary preferences. The exercise-induced changes were associated with regulating food intake as well as encouraging healthier dietary preferences. Such a sequential relationship may assist individuals who feel pressured to improve their diet and physical activity at once, since imposing multiple goals often discourages, rather than motivates people to improve their health behaviors within a busy schedule. More research is required to better elucidate clinical significance and underlying mechanisms involved in the exercise-induced changes in dietary preferences.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgements

This work was supported by award number R01DK062148 from the National Institute of Diabetes and Digestive and Kidney Disease (NIDDK).

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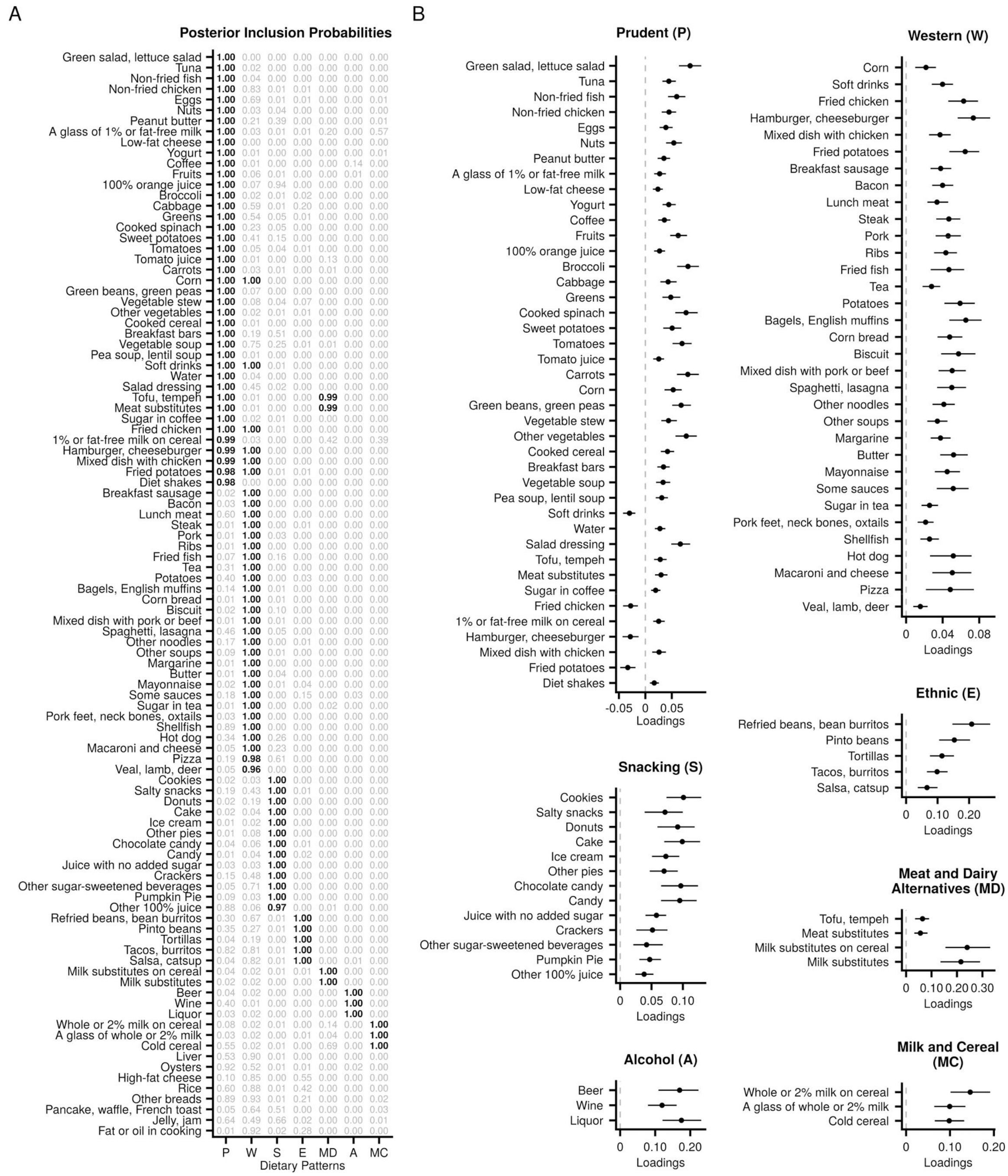

Figure 1.

Dietary patterns among young adults identified in the TIGER study. (A) Posterior inclusion probabilities of individual food-factor pairs. Foods showing posterior inclusion probability > 0.95 (boldface) for each factor were considered in defining dietary patterns. (B) Posterior means of significant factor loadings with 95% credible intervals are displayed for each dietary pattern, respectively.

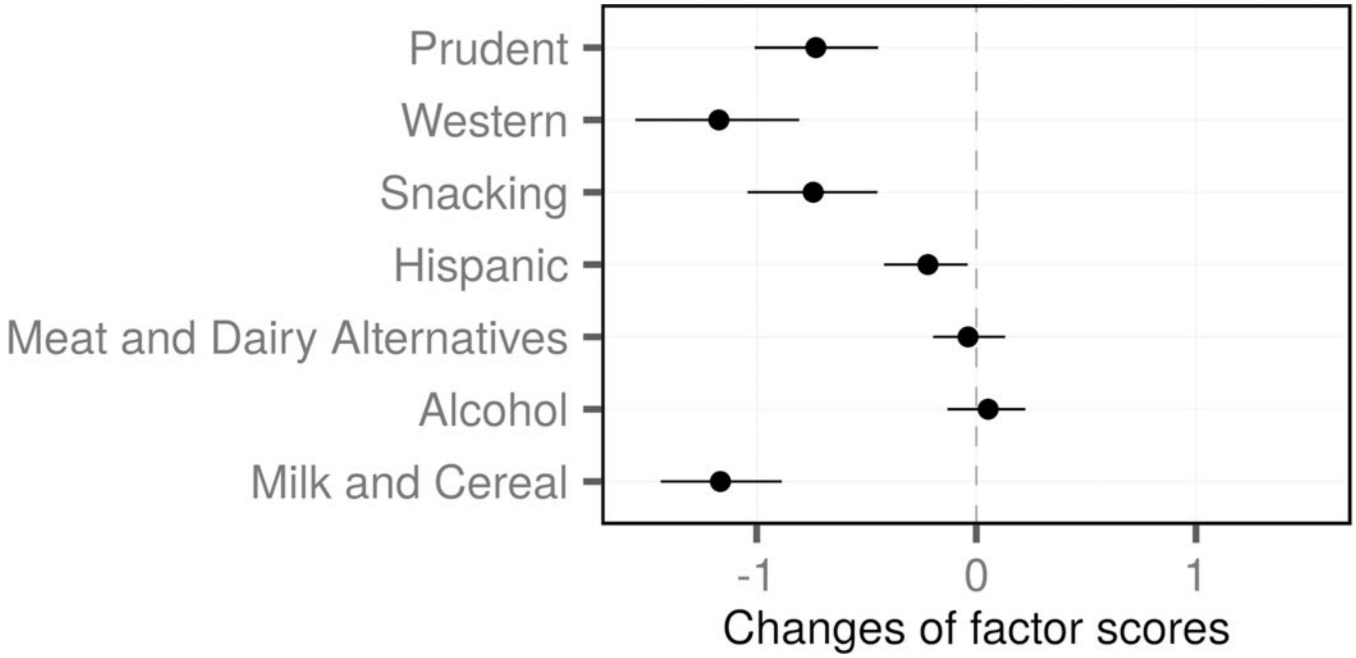

Figure 2.

Exercise treatment effect on dietary preferences based on changes in dietary pattern scores for all participants. Changes of pattern scores were summarized using their posterior means with 95% credible intervals. Most dietary pattern scores were decreased following exercise training, except for the Meat and Dairy Alternative and Alcohol patterns.

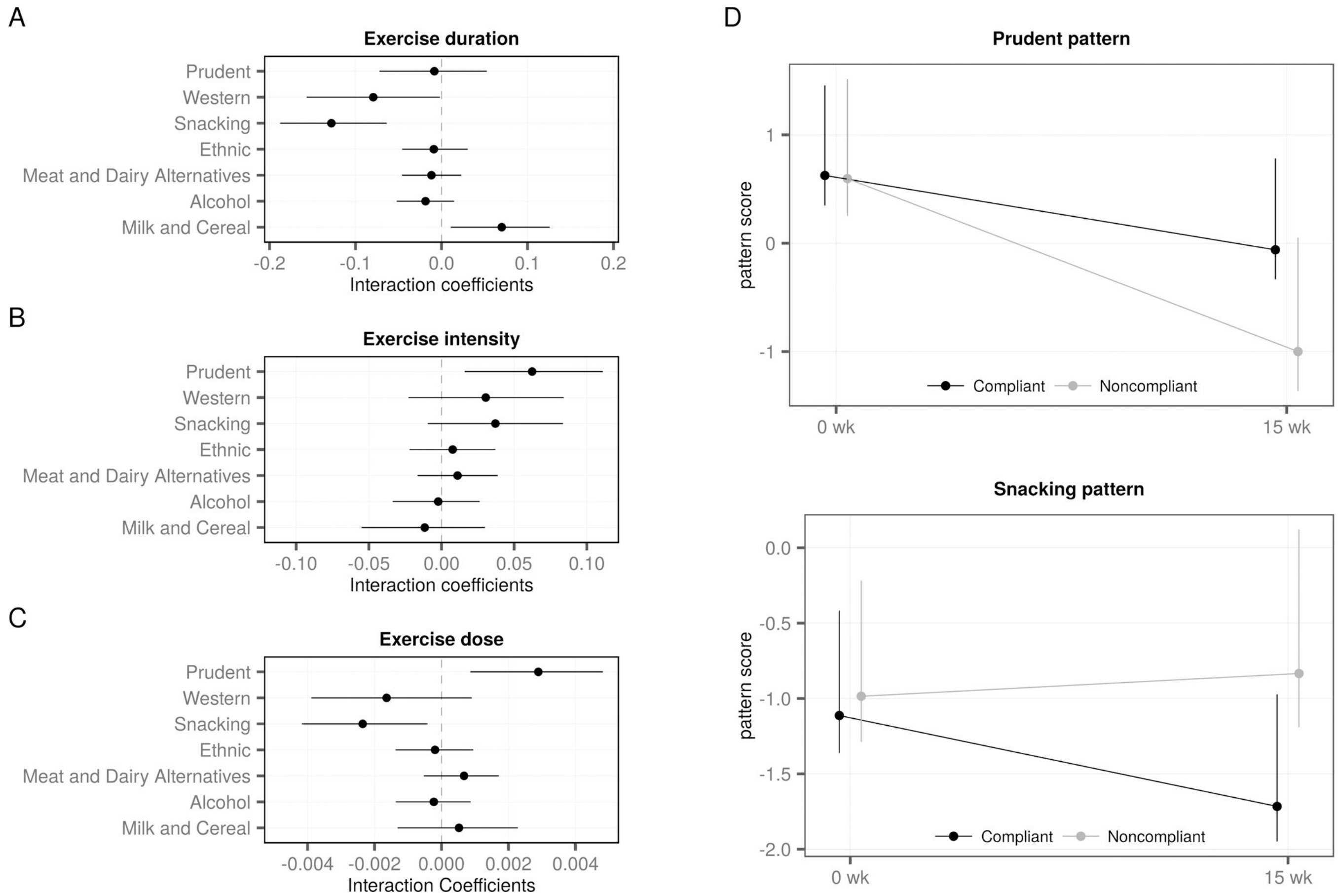

Figure 3.

Influences of exercise characteristics on the treatment effect of exercise intervention on dietary preferences. Subfigures A-C represent how treatment effect on dietary preferences vary by each one-unit increase of exercise duration, intensity, and dose. Results were summarized with their posterior means of 95% credible intervals. (A) Influence of exercise duration (min). (B) Influence of exercise intensity (%HRR). (C) Influence of exercise dose (HRPAS) (D) Changes of the Prudent and Snacking pattern scores by a dose-based exercise compliance status.

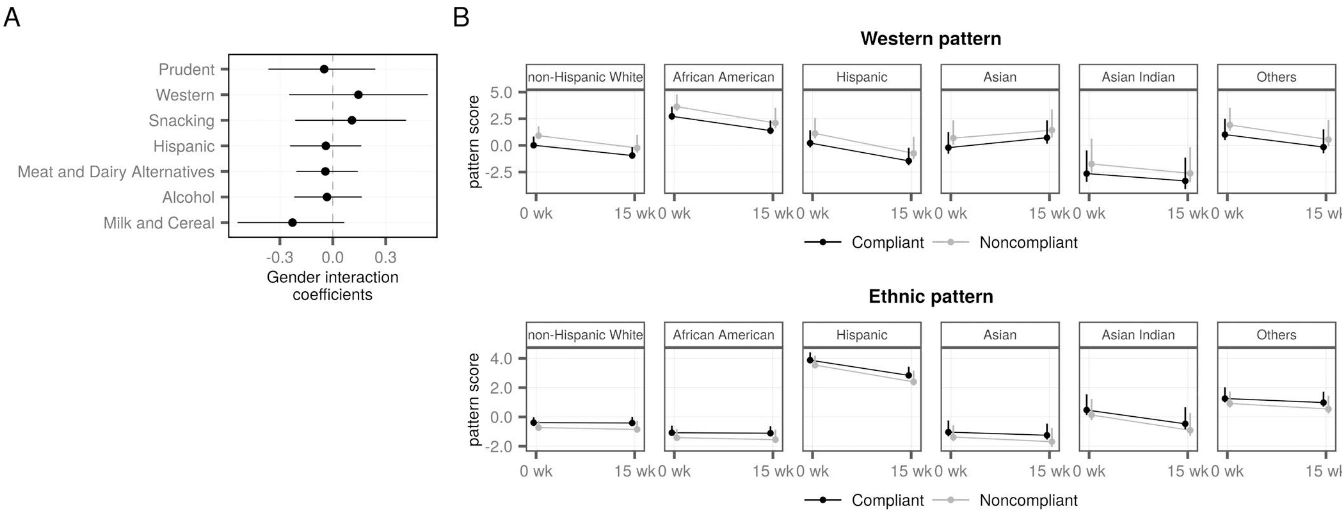

Figure 4.

Influence of gender and race/ethnicity on exercise treatment effect on dietary preferences. Gender and race/ethnicity were dummy-coded where the reference groups were male and non-Hispanic white, respectively. Estimates were summarized using their posterior means with 95% credible interval. (A) Influence of gender on the treatment effect of exercise training. (B) Changes of the Western and Ethnic pattern scores by race/ethnicity.

Table 1.

Descriptive statistics of exercise characteristics and anthropometric variables (n = 2 680).

	Mean (SD)			
	Female		**Male**	
	0 week	**15 week**	**0 week**	**15 week**
Age	21.65 (4.85)	21.99 (4.97)	22.21 (5.13)	22.59 (5.17)
BMI ($kg{\cdot}m^{-2}$)	26.16 (6.21)	25.93 (6.00)	27.08 (5.65)	26.76 (5.41)
Body mass (kg)	68.87 (17.67)	68.39 (17.07)	83.75 (19.79)	82.82 (18.98)
Hip (cm)	102.21 (12.41)	101.72 (11.90)	102.19 (11.52)	100.75 (10.77)
Waist (cm)	76.46 (12.93)	75.45 (11.95)	87.25 (14.94)	85.81 (13.83)
DXA fat (%)	34.26 (7.74)	33.87 (7.63)	22.33 (8.76)	21.62 (8.63)
Exercise Measures				
Mean duration (min/session)	38.19 (3.95)		37.19 (5.70)	
Mean intensity (%HRR)	66.33 (5.71)		67.37 (5.91)	
Total dose (HRPAS)	777.44 (213.67)		769.61 (240.75)	
Attendance rate (%)	83.40 (20.42)		82.59 (21.76)	

*DXA: Dual-energy X-ray absorptiometry