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ORIGINAL RESEARCH

Do Physical Activity, Caloric Intake, and Sleep Vary Together Day to Day? Exploration of Intraindividual Variability in 3 Key Health Behaviors

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Background: Little is known about how daily fluctuations in health behaviors relate to chronic disease risk. The goal of this study was to examine whether variability in physical activity, caloric intake, and sleep is related to body composition (body mass index and body fat percentage). **Methods**: Healthy adults (N = 103; 64% female) were monitored for 7 days to assess physical activity (SenseWear Armband), caloric intake (daily food diaries), and sleep duration and timing (Actiwatch Spectrum). Data were analyzed using correlations (between- and within-subjects correlations) and regression. **Results**: The results demonstrated that variabilities in physical activity, caloric intake, and sleep were unrelated. Caloric intake and sleep variability were unrelated to body composition. At greater levels of physical activity variability, any level of physical activity was protective for body composition. **Conclusions**: These results suggest that among healthy adults, variabilities in health behaviors may be independent of each other, and physical activity variability may be more strongly related to body composition among those who are less active.

Keywords: body mass index, body fat, variation, healthy adults

Regular engagement in healthy behaviors is often cited as important for promoting health and preventing illness.[1] In particular, insufficient physical activity[2] and greater caloric intake[3] are related to worse cardiometabolic health, including greater risk of obesity, cardiovascular disease, and mortality. Evidence suggests that sleep is also associated with body composition, with both short and long sleep duration associated with greater likelihood of obesity.[4] Most of the research targeting these health behaviors focuses on the average engagement in behaviors over time. Although valuable information is gained from this approach, it inherently ignores information about intraindividual variability from day to day in health behavior engagement. To date, little is known about whether variability of health behavior engagement within a person is associated with health and well-being.

Of the variability in health behaviors listed above, variability in sleep has been the most studied. There is growing evidence suggesting that greater sleep variability is associated with poorer subjective sleep quality and some studies suggest that it is associated with poorer cardiometabolic health. For example, greater variability in sleep duration over 5 to 7 days is associated with higher hemoglobin A1c in older adults with insomnia[5] and in adults with type 1 diabetes without insomnia.[6] There is also evidence that sleep timing variability is associated with greater body mass index (BMI)[7] and greater markers of inflammation in older adults.[8] These studies suggest that the variability of sleep is an important marker of health in addition to the mean sleep values.

In comparison with several studies on sleep variability, there is little research on variability among other health behaviors, such as physical activity and caloric intake. One recent study showed that day-to-day physical activity variability is very high, as 50% of the variability in physical activity is due to intraindividual variation.[9] To our knowledge, no studies have examined the associations among variability in physical activity and variabilities in sleep or caloric intake. The question remains whether variable engagement in health behaviors is associated with body composition, including greater BMI and proportion body fat. Studying how variabilities in health behaviors, specifically among sleep, physical activity, and caloric intake, are related to one another and to body composition may increase the field's understanding of how these health behaviors influence cardiometabolic health.

The purpose of this study was to evaluate the characteristics of health behavior variabilities for 3 key health behaviors, such as physical activity, caloric intake, and sleep (duration and timing). Specifically, the goals were (1) to determine whether variabilities, both between- and within-subjects variabilities, are related to the average levels and whether variabilities are related to variabilities in other health behaviors, and (2) to determine whether variabilities in health behaviors are related to measures of body composition (BMI and body fat percentage) in a sample of healthy adults. We hypothesized that greater variability in sleep would be related to body composition (greater BMI and greater percent body fat). Because the extant literature is sparse regarding variability in physical activity and caloric intake, we made no specific hypotheses regarding these variables in relation to BMI and body fat percentage.

Methods

Participants

Participants were recruited to participate in a larger study of circadian timing and metabolic risk in healthy sleepers.[10] Men and women were recruited from the community using flyers and web advertisements. Participants were included if they (1) were between 18 and 50 years of age, (2) had a habitual sleep duration ≥6.5 hours and ≤8.5 hours, and (3) were able to read and write in

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English. Participants were excluded if they had (1) high risk or presence of obstructive sleep apnea, insomnia, or restless legs syndrome as assessed by the screening questionnaires and/or home sleep monitoring; (2) a history of cognitive or other neurological disorders; (3) any major psychiatric disorder; (4) current alcohol or substance abuse as assessed by the screening questionnaires; (5) history of or concurrent unstable or serious medical illness (eg, cancer, diabetes, or cardiovascular disease); (6) current use of psychoactive medications including antidepressants, anxiolytics, neuroleptics, anticonvulsants, hypnotics, stimulants, or beta blockers; (7) shift work or traveled over 2 times zones in the past 6 months; (8) caffeine consumption >300 mg/d; (9) current smoking; or (10) pregnancy or desire to become pregnant during the study period.

Procedures

Screening. Persons interested in the study completed an initial web or telephone screening to rule out self-reported short sleep duration, comorbid conditions, and suboptimal health behaviors (eg, smoking, alcohol, and substance use). Then, prospective participants completed an in-person screening visit where they completed questionnaires. They subsequently completed one night of home sleep apnea screening and 7 days of actigraphy to determine if they met study criteria. After screening data were reviewed, and eligible participants were scheduled for one night in the Clinical Research Unit.

Monitoring Period. Participants completed 7 days of actigraphy, sleep and food diaries, and physical activity monitoring. Participants were asked to keep their habitual bedtimes and wake times at screening within 1 hour of their average screening times.

Laboratory Session. During the 20-hour Clinical Research Unit visit, participants completed a dual-energy X-ray absorptiometry scan, and height and weight were measured by Clinical Research Unit staff after fasting overnight.

Measures

Demographics. Participants self-reported demographic information including age, gender, race, ethnicity, income, employment, and marital status.

Physical Activity. Participants wore the SenseWear Pro Armband monitor (BodyMedia, Inc, Pittsburgh, PA) for 7 days to measure physical activity and energy expenditure. The monitor has several sensors including a triaxial accelerometer, heat flux sensor, skin temperature sensor, near body ambient temperature sensor, and galvanic skin response sensor. The SenseWear monitor has demonstrated accuracy and reliability for physical activity assessment.[11–13] Total physical activity was calculated using SenseWear Professional software (version 8.1; BodyMedia Inc., Pittsburgh, PA). SenseWear recordings were considered valid if participants had at least 3 days of recording with ≥18 hours of wear time daily.

Caloric Intake. The participants recorded time, location, type of food, amount consumed, and the description of each component including brands and restaurant names in food diaries for 7 days. Participants were asked to record foods as their component parts (eg, turkey sandwich = 2 slices of white bread, 3-oz deli turkey, and 1 tablespoon of reduced fat mayo) and to record drinks and condiments. Participants then e-mailed, faxed, or called in diaries daily to ensure that they were completed on time. At the end of the week, staff reviewed food diaries and queried for missing foods and components (eg, cream in coffee, drinks, condiments, cooking with oil, or other missed foods). Three days of food diaries chosen at random (2 weekdays/work days and 1 weekend or free day) were analyzed using the Food Processor software (ESHA, Inc, Salem, OR). Foods not available in the database were found on company or restaurant websites. When caloric information was not available, the closest substitute was used. Total daily caloric intake each day was computed and averaged.

Sleep Duration and Timing. The Actiwatch Spectrum (Philips/Respironics, Inc, Bend, OR) estimated sleep/wake patterns during 7 days of wrist actigraphy at screening and before the laboratory session. Participants wore Actiwatches on their nondominant wrists, which were set with a 30-second epoch length and medium sensitivity. Sleep duration and timing (sleep start time and end time) were calculated using Actiware Sleep software (version 6.0; Philips/Respironics, Inc, Bend, OR) with default settings. Sleep timing was calculated by determining the midpoint time of sleep on each night. Sleep diaries were used to enter bedtimes and wake times into the Actiware software and included in scoring. Off-wrist time was excluded based on the Spectrum's off-wrist detection; a day was not considered valid if any off-wrist time was detected during the sleep period reported on the sleep diary. Participants were included in the analyses if they had at least 5 valid days of actigraphy data.

Body Mass Index. Body mass index (in kilograms per meter square) was calculated using measurements from the laboratory session at the Clinical Research Unit. Height was measured on admission by nursing, and weight was taken in light clothing, without eating or drinking after the morning void.

Body Fat Percentage. Body fat percentage was measured using dual-energy X-ray absorptiometry on a whole-body Hologic scanner (version 13.1; Hologic, Marlborough, MA). Total body fat percent was calculated using automated calculations provided by Hologic.

Statistical Analyses

Statistical analyses were conducted in SAS (version 9.4; SAS Institute, Cary, NC). Descriptive statistics were calculated to examine central tendency and distributions of study variables. Variability for each participant in health behaviors over 7 days was calculated as the SD in the daily value (ie, minutes of physical activity, minutes of sleep, midpoint time of sleep, and total calories). Creating a "trait" variability score is the most common analytical strategy employed by researchers studying variability in night-to-night sleep.[7] Of note, variability of total caloric intake was positively skewed; thus, a log transformation was used to normalize the data.

Missing data analyses were conducted to determine whether individuals included in the sample were missing data at random or not at random. Participants were included in this study if they had BMI and body fat percentage measurements and if they completed at least 2 of the 3 health behavior assessments (sleep actigraphy, physical activity accelerometry, and/or daily food records). One participant was excluded because the Actiwatch recorded 0 minutes of sleep for this person over 3 consecutive days. Included participants were compared with participants not included in the final sample on age, gender, and body size measurements using independent samples t tests and χ^2 analyses (for gender).

Pearson product-moment correlations were used to examine the bivariate relationships between study variables and to examine the relationships among variabilities in health behaviors. Subsequently, 8 moderation regression models were used to examine the interactions of the 3 health behaviors (sleep [duration and timing], physical activity, and diet) on the 2 dependent variables (BMI and body fat percentage). Models controlled for age and gender, included the main effects of average and variability of behaviors, and included the interaction between average and variability of behaviors on the dependent variable. Significant moderation effects were probed by calculating simple slopes at ±1 SD from the mean.

A second analytic approach examined within-person associations among health behaviors. Within-subjects correlations (described by Bland and Altman[14]) were used to examine the relationship among physical activity, caloric intake, sleep duration, and sleep timing. With this method, between-subjects variability is parsed out so that within-subjects variability is all that remains.[14] Compared with the first approach that treats variability like a trait (calculating a SD within a person), the second approach treats each day as an observation (rather than each person as an observation) and examines how variability within a person on one behavior is related to variability within a person on a second behavior.

Results

The final sample included 103 adults (64% female) with a mean age of 26.7 years (SD = 7, min = 18, max = 50). The sample was predominantly white, non-Hispanic (n = 56, 54%), followed by Asian or Pacific Islander (n = 24, 23.3%), black or African American (n = 11, 10.6%), more than one race or ethnic group (n = 8, 7.8%), and Hispanic or Latino (n = 4, 3.8%). The majority of participants were single (n = 87, 84.5%) and only 13% were married or cohabiting (n = 13). The sample was highly educated (bachelor's degree: n = 55, 53.4%; graduate degree: n = 20, 19.4%), and nearly half of the sample were current students (n = 44, 42.7%). Most other participants were employed full (n = 33, 33%) or part time (n = 18, 17.5%), with a median income between US$26,000 and $50,000. Sample descriptive statistics are presented in Table 1.

Overall, the sample was highly active and had a BMI in the normal range. Participants included in the final sample did not significantly differ from those excluded based on age ($P = .53$), gender ($P = .49$), BMI ($P = .34$), or body fat percentage ($P = .40$). Within the final sample, 29 participants were missing valid physical activity data. Participants with missing physical activity data did not have significantly higher BMI ($P = .16$) or body fat ($P = .11$) than participants with valid physical activity data.

Relationship Between Health Behavior Variabilities and Health Behavior Averages

Correlations among the study variables are presented in Table 2. Greater variability in physical activity was related to greater average physical activity duration, and greater variability in caloric intake was related to greater average caloric intake. Variability in sleep duration was not significantly correlated with average sleep duration. However, greater variability in sleep timing was related to greater variability in sleep duration. Furthermore, later average sleep timing was associated with greater variability in sleep timing. There were no significant relationships among variability in sleep duration or timing, variability in physical activity, or variability in caloric intake. Greater sleep duration was associated with shorter average physical activity duration.

Relationship Between Health Behavior Variabilities and Averages With BMI and Body Fat

Lower average physical activity duration, less physical activity variability, and greater average caloric intake were associated with greater BMI. Greater average sleep duration, lower average physical activity duration, less physical activity variability, and less caloric intake variability were associated with greater body fat percentage.

Health Behavior Variabilities as Moderators of Relationships Between the Averages and Body Composition

Physical Activity. There was a significant interaction between average physical activity and physical activity variability on BMI ($\beta = 0.29$, $P = .02$; see Figure 1). At low levels of average physical activity, greater variability was related to lower BMI ($b = -0.04$, $P < .001$). At high levels of average physical activity, the relationship between variability and BMI was weaker but still negative and significant ($b = -0.02$, $P < .01$).

Table 1 Descriptive Statistics

Variable	n	Mean	SD	Min	Max
Body mass index, kg/m^2	103	24.2	4.3	16.0	38.2
Body fat, %	103	30.5	8.1	15.6	54.1
Sleep duration, min					
Daily average	99	439.1	50.6	303.4	555.2
Day-to-day variability, SD	99	66.4	30.1	15.9	170.6
Sleep timing, time					
Daily average	99	4:37	1:26	2:31	9:56
Day-to-day variability, SD	99	0:49	0:26	0:10	2:41
Physical activity, min					
Daily average	74	148.4	87.8	8.0	517.3
Day-to-day variability, SD	74	60.0	37.4	11.3	187.0
Caloric intake, kcal					
Daily average	101	1941.9	674.2	665.4	4336.7
Day-to-day variability, SD	101	537.2	447.7	39.7	3266.2

Table 2 Pearson Correlations Among Study Variables

Variable	Age	Female	BMI	Body fat	Sleep duration (Avg)	Sleep duration (Var)	Sleep timing (Avg)	Sleep timing (Var)	Physical activity (Avg)	Physical activity (Var)	Caloric intake (Avg)
Age	–										
Female	0.03	–									
BMI	0.23*	–0.03	–								
Body fat	0.04	0.67***	0.54***	–							
Sleep duration (Avg)	0.14	0.19	0.16	0.23*	–						
Sleep duration (Var)	–0.16	0.08	–0.04	0.06	–0.17	–					
Sleep timing (Avg)	–0.32**	–0.14	–0.18	–0.10	–0.06	0.33***	–				
Sleep timing (Var)	–0.24*	0.09	–0.14	0.05	–0.14	0.46***	0.26**	–			
Physical activity (Avg)	–0.08	–0.22	–0.50***	–0.48***	–0.28*	0.01	0.02	0.15	–		
Physical activity (Var)	–0.24*	–0.10	–0.46***	–0.32**	–0.09	–0.03	0.13	0.12	0.75***	–	
Caloric intake (Avg)	0.01	–0.33***	0.19*	–0.16	0.01	–0.15	0.04	–0.14	–0.03	–0.12	–
Caloric intake (Var)	0.04	–0.26**	0.04	–0.24*	–0.05	–0.05	–0.06	–0.10	–0.06	–0.07	0.51***

Abbreviations: Avg, average; BMI, body mass index; Var, variability.
*$P < .05$. **$P < .01$. ***$P < .001$.

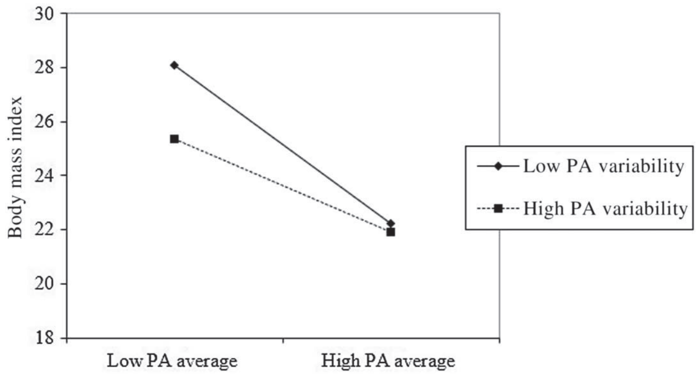

Figure 1 — Interaction between PA average and variability on body mass index. PA indicates physical activity.

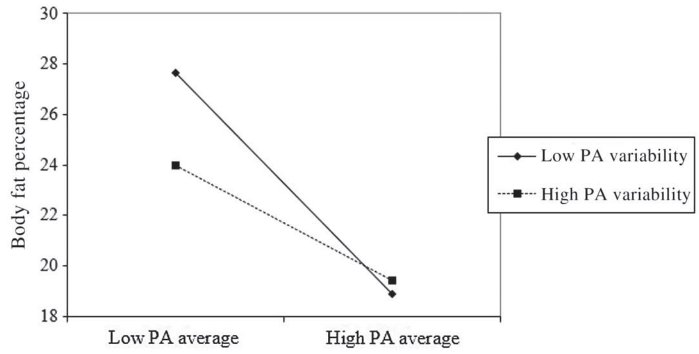

Figure 2 — Interaction between PA average and variability on body fat percentage. PA indicates physical activity.

Similar results were seen when examining the associations between physical activity and body fat percentage. There was a significant interaction between average physical activity duration and physical activity variability on body fat ($\beta = 0.27$, $P = .01$; see Figure 2). At low levels of average physical activity, greater variability was related to lower body fat percentage ($b = -0.05$, $P < .001$), and this relationship was weaker but still significant at high levels ($b = -0.03$, $P < .01$).

Caloric Intake. There was not a significant interaction between average caloric intake and caloric intake variability on BMI ($\beta = -0.13$, $P = .20$) or body fat percentage ($\beta = -0.04$, $P = .57$).

Sleep. There was not a significant interaction between average sleep duration and sleep variability on BMI ($\beta = 0.05$, $P = .60$) or body fat percentage ($\beta = 0.01$, $P = .93$). Similarly, there was not a significant interaction between average sleep midpoint time and variability in sleep midpoint time on BMI ($\beta = 0.00$, $P = .99$) or body fat percentage ($\beta = 0.08$, $P = .36$).

Associations Among Health Behaviors Within Each Day

Within-subjects correlations are presented in Table 3. Correlations revealed that on days when individuals went to sleep later than average, they also engaged in less physical activity than average, consumed more calories than average, and slept for a longer period of time than average. There were no associations within individuals among physical activity duration, caloric intake, and sleep duration.

Table 3 Within-Subjects Correlations Among Health Behaviors

	Physical activity	Caloric intake	Sleep duration
Physical activity	–		
Caloric intake	−.05	–	
Sleep duration	−.02	.02	–
Sleep timing	−.08*	.13*	.23**

*$P < .05$. **$P < .001$.

Discussion

The purpose of this study was to examine the associations among health behavior variabilities and (1) health behavior averages, (2) variabilities of other health behaviors, and (3) measures of body composition in healthy sleepers. The primary finding was that greater variability in physical activity attenuated the relationship between average physical activity and cardiometabolic risk factors, whereas variabilities in sleep and caloric intake did not. Interestingly, in contrast to the hypothesis, there were no relationships among trait variabilities in health behaviors, suggesting that just because a person had greater variability in one behavior did not necessarily indicate that they were more likely to be variable in other health behaviors. However, when examining variability within a person, it was found that when individuals went to bed later than they typically did, they also engaged in less physical activity than normal, ate more calories than normal, and slept longer than normal.

Results revealed that participants who engaged in less physical activity overall (ie, low average physical activity) did so consistently (ie, low physical activity variability), whereas individuals who engaged in greater physical activity (ie, high average physical activity) were also more variable in their day-to-day activity. In addition, greater physical activity variability attenuated the relationship between average physical activity and body composition. Previous research has shown that daily physical activity variability is high,[9] and time spent sedentary is strongly and adversely associated with markers of cardiometabolic health.[15] In particular, insufficient physical activity has been associated with increased risk of mortality.[2] The present results extend the extant literature and suggest that variability in physical activity may be more strongly related to body composition among those who are less active. Thus, at lower average levels of physical activity, any activity (ie, high variability) is related to a leaner body composition compared with no activity. This supports the recommendation that doing some physical activity is better than doing no physical activity for maintaining a lean body mass.

This study also found that greater average caloric intake was associated with greater variability in caloric intake. That is, people who ate less calories daily (ie, low average caloric intake) tended to do so consistently (ie, low caloric intake variability), whereas individuals who ate more calories on average (ie, high average caloric intake) were more variable in their day-to-day caloric intake. This suggests that greater variability in caloric intake may essentially contribute to greater BMI or body fat through an increase in average calories consumed.

This finding is somewhat contrary to previous research that has identified increased caloric intake as a primary driver of the obesity epidemic.[16] Some studies have gone so far as to suggest that caloric intake may be more strongly tied to body composition than physical activity.[3] Thus, the present findings, showing that physical activity was more strongly associated with BMI and body fat than a snapshot of caloric intake in a healthy sample, are in contrast with expectations. However, it should be noted that this study's sample included healthy adults with average BMI falling within the normal range[17] who provided only 1 week of food diaries. Thus, it is possible that characteristics of the present sample precluded the ability to detect associations between caloric intake and body composition.

In this sample of adults who were selected to have a normal average sleep duration, average sleep duration was not associated with sleep variability. However, later average sleep timing was associated with greater variability in sleep timing and sleep duration. Although participants in this study exhibited similar average sleep duration and variability to those reported in other studies of healthy adults,[18] duration of sleep was not related to nightly variability. Furthermore, associations among average sleep duration, sleep variability, and body composition were not supported. This is contrary to previous research, which has shown that greater sleep variability is associated with higher hemoglobin A1c[5,6] and greater BMI[5] in patients with insomnia or type 1 diabetes. As with caloric intake, it is possible that characteristics of the present sample, including its exclusion of poor sleepers and individuals with significant medical comorbidities, prohibited the detection of relationships between sleep characteristics and body composition in this particular sample.

Despite the lack of associations related to average sleep and variability in this study, there is growing evidence that intraindividual daily variability in sleep duration is substantial,[18,19] and greater sleep variability has been associated with a number of coincident negative outcomes including poorer sleep quality,[5,20] greater stressful life events,[18] and lower psychological well-being.[17,21] Thus, continued study and clarifications of the implications of sleep duration variability are warranted.

Finally, this study found that when an individual had later than their own sleep onset time, this was associated with greater caloric intake, fewer minutes of physical activity, and longer sleep duration the same day. This supports prior research that suggests a potential association between sleep variability and eating behavior.[22–24] More specifically, there are several studies[25–27] demonstrating poorer health behaviors among individuals with late sleep timing and increased caloric intake with experimentally delayed bedtime,[27,28] but this study demonstrates that even within an individual, a later than typical bedtime was associated with changes in physical activity, sleep, and eating behaviors in their naturalistic environment.

This study begins to address a specific gap in the literature, whereby we know relatively little about how health behavior variabilities relate to one another and to markers of body composition. Future research will benefit from continued assessment of these relationships. In particular, it will be beneficial for studies to target populations at increased risk for cardiometabolic events, including those with hypertension, hyperlipidemia, sleep-related disorders such as insomnia and sleep-disordered breathing, and obesity.

Strengths and Limitations

Strengths of this study include the use of objective measures of sleep and physical activity, eliminating potential self-report bias for these activities. Although caloric intake was self-reported by participants via food diaries, all caloric intake data were reviewed by staff who queried participants for missing foods and components (eg, cream in coffee, drinks, condiments, cooking with oil, or other missed foods), which increases the reliability of these data.

This study also has important limitations. The sample was comprised of young, healthy, highly educated, and highly active adults without severely short or long sleep durations. It is possible that the present sample characteristics inhibited the ability to detect associations between some health behavior variabilities and markers of cardiometabolic health that may exist among populations with less optimal health behavior engagement. In addition, participants were asked to keep their habitual bedtimes and wake times during the observation period within 1 hour of their average screening times. However, it should be noted that variability in sleep duration in this sample was only slightly less variable than in a sample of people with insomnia (SD = 70 min; current sample SD = 66 min).[5] In addition, the study period was limited to 7 days of measurement, which may be too short to fully capture the range of variability in health behavior engagement. Finally, there are important psychological variables, such as mood and perceived stress, which may influence variability that were not measured in this study. These variables would be important additions to future research.

Conclusions

This study suggests that, among healthy adults, variability in physical activity may be more related to body composition among those who are less active. That is, some physical activity is better for body composition than no physical activity. Sleep variability and caloric intake variability were not related to BMI or body fat percentage in this sample of healthy adults. Further research is needed to clarify relationships among variabilities in health behaviors and as they relate to body composition and other cardiometabolic outcomes, particularly among populations at greater risk for cardiometabolic disease.

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