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Compensation or displacement of physical activity in middle school girls: The Trial of Activity for Adolescent Girls

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Abstract

The “activitystat” hypothesis suggests that increases in moderate-to-vigorous physical activity (MVPA) are accompanied by a compensatory reduction in light physical activity (LPA) and/or an increase in inactivity in order to maintain a consistent total physical activity level (TPA).

Objective—The purpose of this study was to identify evidence of compensation in middle school girls.

Subjects—Participants were 6,916, 8th grade girls from the Trial of Activity for Adolescent Girls (TAAG).

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Design—Inactivity and physical activity were measured over 6- consecutive days using accelerometry (MTI Actigraph). A within-girl, repeated measures design was used to assess associations between physical activity and inactivity using general linear mixed models.

Results—Within a given day, for every one MET-minute more of inactivity, there was 3.18 MET-minutes (95% confidence interval: −3.19, −3.17) less of TPA (activity > 2 METS) on the same day. Daily inactivity was also negatively associated with TPA on the following day. Each additional minute of MVPA was associated with 1.85 minutes less of inactivity on the same day (95% confidence interval: −1.89, −1.82). Daily MVPA was also negatively associated with inactivity the following day.

Conclusion—Our results, based on 6-days of observational data, were not consistent with the "activitystat" hypothesis, and instead indicated that physical activity displaced inactivity, at least in the short term. Longer intervention trials are needed, nevertheless our findings support the use of interventions to increase physical activity over discrete periods of time in middle school girls.

Keywords

accelerometry; adolescent; physical activity; inactivity

INTRODUCTION

It has been hypothesized that an "activity center" or "activitystat" within the central nervous system controls an individual's amount of physical activity over time, and therefore daily energy expenditure (1). Physical activity may be kept within narrow tolerance limits in order to maintain energy balance, much like internal body temperature, pH, and blood pressure (1). The "activitystat" would keep total physical activity constant by increasing or decreasing the frequency, intensity, and/or duration of time spent in an intensity level of physical activity or in inactivity to compensate for previous activity. For example, on a day that an individual jogged for 30 minutes, they might increase the amount of time spent being sedentary; whereas on a day that the same individual did not jog, they might increase the amount of time spent walking and decrease the amount of time in sedentary activities. These "trades" would result in the same amount of total activity, and are assumed to be internally driven, rather than purposively calculated.

Figure 1 is a graphic illustration of how the "activitystat" could maintain a set-point total physical activity level. In this example, as minutes (y-axis) of moderate to vigorous physical activity (MVPA) increases across the three days, light physical activity (LPA) decreases, and total physical activity, expressed in terms of intensity weighted minutes, is unchanged across the three days. As can be seen in Figure 1, the total amount of physical activity is not affected by the inactivity level. Despite total physical activity remaining constant, inactivity varies on each of the three days to compensate for the changes in LPA and MVPA. The "activitystat" results in compensation for the periods of inactivity through increases in the intensity of activity during the rest of the day in order to maintain the total physical activity set-point.

The “activitystat” hypothesis is in opposition to the displacement hypothesis. The displacement hypothesis suggests that television watching and other sedentary behaviors displace physical activity (2). Increased time spent inactive has been suggested to be a primary factor contributing to the current increases in obesity seen in adolescents (3-5), since inactivity is associated with low energy expenditure. If inactivity displaces physical activity, then an inverse relationship between inactivity and MVPA or total physical activity would be expected. However, there are few data to support the existence of such relations (6).

A limited number of observational (7-9) and experimental studies (10, 11) have examined the compensation phenomenon in children and youth with inconsistent findings. The present study uses a repeated measures approach to examine the relations between inactivity, LPA, MVPA, and total physical activity over 6 consecutive days in adolescent girls. The goal of the study was to determine if relations exist between inactivity, total physical activity, and the components of total physical activity that are suggestive of compensatory changes over a period of one to two days in physical activity or displacement of physical activity by inactivity. We hypothesized that compensation might occur within a given day, or might be manifest on the following day. Therefore, evidence of compensation was sought within a day and on the subsequent day. Specific questions addressed include: 1) is inactivity associated total physical activity?; 2) is MVPA associated with inactivity?; and 3) is MVPA associated with LPA? To our knowledge this is the first study to examine these questions using observational data from repeated daily measures in a free-living population and an objective measure of physical activity and inactivity.

MATERIALS AND METHODS

Study Design

Data were collected as part of the Trial of Activity for Adolescent Girls (TAAG). TAAG is a multi-center group-randomized trial designed to test an intervention to reduce the usual decline in moderate to vigorous physical activity in middle-school girls (12, 13). TAAG has six field centers (at the Universities of Arizona, Maryland, Minnesota, and South Carolina; San Diego State University; and Tulane University). The project was coordinated by the University of North Carolina, Chapel Hill and the project office at the National Heart, Lung, and Blood Institute collaborated on the study. Girls were recruited from six middle schools within each field center for a total of 36 schools. The parent or guardian of each participant provided written informed consent and girls provided assent. The study was approved by each participating universities’ Human Subjects Review Board.

Participants

The TAAG design included two cross-sectional samples of 8th grade girls, one drawn in the spring of 2005, and the second drawn in the same schools in the spring of 2006 (12). In 2005, 3,440 girls had complete demographic, body composition, and physical activity data, while 3,476 girls in 2006 had complete data. A total of 6,916 girls were included in the current analyses.

Measurements

Physical activity and inactivity were assessed using the MTI Actigraph accelerometer model 7164 (Manufacturing Technologies Inc., Fort Walton Beach, Florida). Girls were instructed to wear the accelerometer on a belt around their waist over their right hip. Girls wore the Actigraph for 6 complete days and were asked not to remove the Actigraph except when sleeping, bathing or swimming. Activity counts were accumulated over 30-second epochs during the 6 days. Actigraph data were processed using methods described by Treuth et al. (14). Missing Actigraph data were imputed using the expectation maximization (EM) algorithm (15). Previous work in the TAAG cohort determined that metabolic equivalent (MET) threshold ranges of 0- 2.09, 2.1-4.59, and ≥ 4.6 METs best discriminated between activities classified as inactive, light, and moderate-to-vigorous activity, respectively (14). These MET ranges corresponded to accelerometer count ranges of 0-50, 51-1499, and > 1500 counts/30-second interval for inactivity, light, and moderate-to-vigorous activity, respectively (14). METs are the ratio of the work metabolic rate to the resting metabolic rate, with one MET defined as the equivalent to the energy cost of sitting quietly or roughly to 3.5 ml/kg/min (16). MET-weighted minutes were calculated as the sum of the MET values for each 30-second epoch within a given intensity range divided by 2 (to convert 30-second intervals to minutes).

Three approaches were used to quantify daily LPA, MVPA and total physical activity: 1) MET-weighted minutes; 2) absolute minutes; and 3) percentage of monitored time (number of hours valid data was recorded each day). Since inactivity has a MET value of 1, absolute minutes spent being inactive and MET-minutes of inactivity have the same value, therefore we quantified inactivity using only two approaches: 1) minutes spent inactive and 2) percentage of monitored time spent inactive.

Body mass was measured while wearing light clothing by use of an electronic scale (Seca, Model 770, Hamburg, Germany). Height was assessed without shoes using a portable stadiometer (Shorr Height Measuring Board, Olney, MD). Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. Percent body fat was estimated from anthropometric measures using an equation that was developed by TAAG investigators for use in middle school girls (17).

Race/ethnicity was measured using a self-report checklist and categorized as (1) Caucasian (White, non-Hispanic), (2) African-American, (3) Hispanic, (4) Asian/Pacific Islander, and (5) Other. A proxy measure of socio-economic status (SES) was assessed at the school level using the proportion of students who received free or reduced cost lunch during a given school year.

Statistical analysis

Statistical analyses were conducted using SAS version 9 (SAS Institute, Cary, NC). A within-girl repeated measures design was used to assess associations between total physical activity and physical activity intensity patterns using general linear mixed models. This design allowed a separate intercept and slope to be estimated for each participant using data from 6-days of measurement. Random effects of field center, school within field center, and girl within school within field center were used to account for the expected correlations between schools within a field center, girls within a school, and the 6-days of measurement within a girl.

For all models covariates were treated as fixed effects. BMI, % body fat, age, SES, and total hours of monitored time on a given day (centered at mean monitored time, 14 hours) were examined as continuous variables and race/ethnicity, day of the week, and year of study (2005 or 2006) as categorical variables. Models in which physical activity was expressed in MET-minutes or minutes included only race/ethnicity, day of week, year of study, and monitored time. Inclusion of other covariates did not improve the fit of the models (likelihood ratio test, $P>0.05$), and none of the estimates changed by more than 2% when these variables were included. The same covariates were incorporated in the models assessing physical activity as a percentage of monitored time, except that monitored time was not included as a covariate.

RESULTS

Table 1 shows descriptive characteristics of the 6,916 girls included in the current analyses. Participants averaged 14 years of age, were predominantly non-white (53.7% non-white), and approximately one-third of the population was overweight or obese. All physical activity and inactivity variables and monitored time presented are the mean daily values over the 6-days of measurement. On average, participants spent more than 60% of each day inactive with only 3% (or 22 minutes) of time spent in MVPA per day.

Pearson correlations between inactivity, LPA, MVPA, and total physical activity are shown in Table 2. Whether physical activity or inactivity was expressed as minutes, MET-minutes, or as a percentage of the day, the direction of each of the corresponding associations was similar. A negative association was observed between inactivity and LPA, MVPA, and total physical activity. MVPA was positively associated with LPA and total physical activity.

Since monitored time is the sum of inactivity and activity, as one of these components increases the other must decrease the exact same amount, hence the correlation of −0.99 between inactivity and total physical activity as a percentage of monitored time. In terms of absolute minutes there is variation in monitored time from one day to the next. In this association it is possible to increase inactivity by a given amount and have a decrease in total PA that is only a fraction of the increase in inactivity simply by wearing the monitor for a longer period of time. For example, it is possible to increase inactivity 100 minutes from day 1 to day 2, while only decreasing total physical activity by 60 minutes by wearing the monitor 40 minutes longer on day 2 than on day 1. A similar association exists for MET-minutes. MET-minutes assess the intensity of activity, in addition to the time of activity, which may explain why correlations with MET-minutes are somewhat higher than those for absolute minutes.

In Table 3 coefficients estimate the same day average change in the dependent variable associated with a one-unit increase in the independent variable within girls. For example, the coefficient estimating the impact of inactivity on total PA was −3.18. This means that for every MET-minute more of inactivity, total PA on the same day was 3.18 MET-minutes less after accounting for the amount of time the monitor was worn on each day. Likewise, every additional 1 minute of MVPA on a given day was associated with 1.85 minutes less of inactivity on the same day, as well as 0.85 minutes more of LPA. The coefficients for each of the three models were statistically significant ($P < 0.01$), whether physical activity was expressed as minutes, MET-minutes, or percent of day. Additionally, all of the coefficients were in a similar direction regardless of how physical activity was expressed.

Similar models using vigorous physical activity (VPA; ≥ 2600 counts/30-second interval) instead of MVPA were also tested (data not shown). Associations with VPA were in the same direction as the models that included MVPA, but the magnitude of the coefficients was much smaller and not always statistically significant. This may have been because of the small amount of VPA in this population (mean=5.0 minutes).

Table 4 displays the results of analyses analogous to Table 3 except that changes in the independent variable on one day were used to predict changes in the dependent variable the following day, rather than on the same day. For example, for every additional MET-minute (or minute) of inactivity on a given day, there was 0.80 MET-minutes less of total PA the following day. As in the same day analyses (Table 3), the coefficients for each of the models was statistically significant ($P < 0.01$) regardless of how physical activity was expressed. Compared to the same day analyses, the coefficients for the following day were markedly reduced; however, the associations were all in the same direction as the analogous models in the same day analyses. Also shown in Table 4 is the association between MVPA on a given day and MVPA on the subsequent day. This association was statistically significant, and varied between 0.22 and 0.24.

Separate analysis of weekend days and weekdays (data not shown) resulted in estimates in the same direction and of similar magnitude, so it is unlikely that the day of the week played an important role in whether or not compensation occurred. For example, the coefficient for inactivity predicting total physical activity (MET-minutes) on weekdays was −3.18 (95% confidence interval (CI): −3.19, −3.16), while on weekends the coefficient was −3.14 (95% CI: −3.16, −3.12).

DISCUSSION

This study examined associations between inactivity, total physical activity, and the components of total physical activity in order to determine whether relationships indicative of compensatory changes were present in adolescent girls. The findings indicated that higher amounts of inactivity on a given day were associated with decreased total physical activity, higher MVPA was associated with less inactivity, and higher MVPA was also associated with higher levels of light physical activity. Additionally, MVPA on a given day was positively associated with MVPA on the following day. Taken together these results lead us to conclude that compensation in physical activity did not occur within a given day or on the following day. Our results do not support the “activitystat” hypothesis, but do support the hypothesis of displacement of physical activity by inactivity.

The number of minutes monitored is the sum of the minutes of inactivity assessed and the minutes of total physical activity measured (LPA and MVPA). Whether expressed in minutes or percent of time monitored, as inactivity increased total physical activity decreased, and the coefficients for the associations were equal to −1. In other words, with a one minute increase in inactivity, activity decreased by one minute. The use of the MET-weighted model demonstrated that the inverse relationship between inactivity and total physical activity was not due only to an exchange of minutes, but that greater inactivity was associated with a lower intensity of activity on a given day.

Because the temporal characteristics of hypothesized compensation were not known, and because of concerns about exchanges of minutes within a given day, we examined the impact of activity patterns on one day on the activity patterns of the following day. Results for the following day analyses suggested that compensatory changes did not occur due to physical activity or inactivity on the previous day. All relationships were statistically significant; however, the coefficients for some of the associations were quite small. Nevertheless, even a null association between these variables would be suggestive of a lack of compensation, as we would expect an inverse association between LPA and MVPA in order to maintain total physical activity at a set-point.

The impact of the associations found here can be illustrated through estimates of energy expenditure. The mean energy cost of a moderate-to-vigorous activity such as a brisk walk is 21.5 kJ/min (5.15 kcal/min) for the participants in this study, while the mean energy cost of LPA and inactivity are 11.6 kJ/min (2.8 kcal/min) and 8.0 kJ/min (1.9 kcal/min), respectively (18). Since each additional minute of MVPA was associated with 1.85 minutes less of inactivity and 0.85 minutes more of LPA, an intervention that increases MVPA by 5 minutes may result in an increase in energy expenditure of 82.7 kJj/day (19.8 kcal/day). Although this may seem a trivial change in energy expenditure, we have previously demonstrated that small increases in MVPA are associated with decreases in percent body fat over a 2-year period in middle school girls (19).

Two experimental studies have examined compensation in physical activity in youth. Dale et al. (11) used accelerometry to compare physical activity after school in third- and fourth-grade children on days when activity during PE class was restricted and days when PE activity was not restricted. No compensatory increases in physical activity were found in those who had restricted activity during the day. In the second study, Blaak and colleagues (10) found a 12% increase in total daily energy expenditure (measured via doubly-labeled water) in a small group of obese 10-11 year old boys who had participated in a 4 week cardiovascular training program. Half of the increase in daily energy expenditure was attributed to an increase in energy expenditure that was not during the training. Thus, there was an increase in non-exercise physical activity outside of the training program not a compensatory decline (10).

In contrast, several observational studies have suggested that individuals compensate for periods of increased MVPA by increasing inactivity or light activity to the extent that total physical activity is unaffected. Wilkin et al. (7) demonstrated that total physical activity levels were similar in children from schools with widely different hours of physical education class, suggesting that those who had less physical education obtained additional activity at other times to make-up the difference between groups. At least two studies (7, 8) have examined compensation by contrasting children who walk to school with those who were driven to school. The investigators found greater physical activity during the time of the trip to school in the walkers compared to those driven to school. However, total physical activity over the entire measurement period was not different between the walkers and non-walkers in these studies, suggesting that the walkers decreased their physical activity during the rest of the day.

Each of the prior studies reported mean data for groups, and did not specifically examine relationships within individuals. Our use of repeated measures within individual girls allowed us to examine the associations between inactivity and total physical activity and its components within participants across each of the 6 days of measurement. We believe this to be a strength of the current study.

Previous studies that have examined the associations between inactivity and physical activity have quantified inactivity via self-report of a selected number of sedentary behaviors (6); in particular television viewing, computer use, and video game playing. It may be that focusing on a few sedentary behaviors, even if they are the most prevalent, does not provide an accurate account of an individual’s total inactivity, resulting in inconsistent associations between inactivity and physical activity in these studies. Other sedentary behaviors of adolescents, such as talking on the phone, reading, or listening to music, should be considered. Also, there is some evidence to indicate that physical activity and inactivity are distinct behaviors with dissimilar determinants (5, 20, 21), and this may impact the relationships found between activity and inactivity in youth.

Our use of accelerometry provided a measure of all time spent inactive, and avoided the possible bias inherent in self-reported data (22). Use of accelerometry also allowed us to quantify minutes spent in various intensities of physical activity, as opposed to doubly-labeled water which provides only a measure of total physical activity estimated from energy expenditure. Another strength of this study is that we used population specific accelerometer intensity cut points to quantify physical activity and inactivity (14). We studied a large and ethnically diverse sample of girls who were drawn as random samples from 36 schools in 6 different states. Nevertheless, since we studied only girls, the results cannot be generalized to boys.

This study stands in opposition to the “activitystat” hypothesis, but suggests increasing inactivity may displace MVPA. These results in middle school girls support the use of interventions that increase physical activity over discrete periods of time, such as in physical activity classes or after school activities. Our work indicates that the gains in minutes of activity acquired during those events are not expected to be dissipated by later declines in activity over a period of one to two days. Whether or not these results persist over extended periods remains to be seen. Longitudinal randomized trials investigating the effects of adding or reducing specific amounts of physical activity or inactivity, and incorporating precise measures of energy expenditure and energy intake along with physical activity are needed to further understand the complex relations between physical activity and inactivity.

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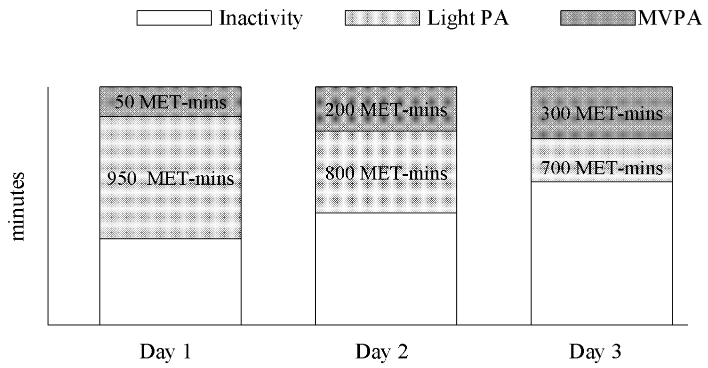

Total PA =	1000 MET-mins	1000 MET-mins	1000 MET-mins
MVPA =	50 MET-mins	200 MET-mins	300 MET-mins
Light PA =	950 MET-mins	800 MET-mins	700 MET-mins

Figure 1.

Demonstration of “activitystat.” As MVPA increases across the three days, there is a compensatory decline in LPA and an increase in inactivity in order to maintain the set-point for total physical activity.

Table 1

Descriptive Characteristics of selected 8th grade TAAG Participants, 2005-2006 (N=6,916).

	Mean (SD) or %
Age (years)	14.0 (0.5)
BMI (kg/m^2)	22.8 (5.3)
BMI Status (%)	
Normal weight	65.5
Overweight	17.0
Obese	17.5
Body Fat (%)	31.4 (8.4)
Race/ethnicity (%)	
White	46.3
Hispanic	21.6
African-American	19.8
Asian/Pacific Islander	5.2
Other	7.1
Inactivity	
Minutes/day	513.9 (64.3)
% of day	61.6 (6.1)
Light Physical Activity	
Minutes/day	295.7 (50.9)
MET-minutes/day	777.9 (138.1)
% of day	35.8 (5.6)
MVPA	
Minutes/day	21.5 (11.0)
MET-minutes/day	130.9 (73.0)
% of day	2.6 (1.3)
Total Physical Activity	
Minutes/day	317.2 (55.2)
MET-minutes/day	908.8 (177.1)
% of day	38.4 (6.1)
Monitored time (hours/day)	13.9 (1.0)

Abbreviations: BMI – body mass index; MET- metabolic equivalent; MVPA- moderate-to-vigorous physical activity

Table 2

Pearson Correlations for Physical Activity Intensities and Total Physical Activity Expressed as Minutes, MET-minutes, and Percent of Monitored Time in selected 8th grade TAAG Participants, 2005-2006 [*].

	Inactivity	LPA	MVPA
Minutes			
Inactivity	1		
LPA	−0.54	1	
MVPA	−0.39	0.30	1
Total PA	−0.57	0.98	0.48
MET-minutes			
Inactivity	1		
LPA	−0.60	1	
MVPA	−0.37	0.65	1
Total PA	−0.60	0.99	0.68
% of Monitored time			
Inactivity	1		
LPA	−0.97	1	
MVPA	−0.50	0.31	1
Total PA	−0.99	0.98	0.50

Abbreviations: LPA- light physical activity; MET- metabolic equivalent; MVPA- moderate-to-vigorous physical activity; Total PA- total physical activity

[*] $P < 0.001$ for all correlations

Table 3

Associations Between Selected Physical Activity Measures for Analyses Comparing Variables on the Same Day in Selected 8th Grade TAAG Participants, 2005-2006*.

	MET-minutes[a]		**Minutes**[a]		**% of Monitored Time**[b]	
	β	**95% CI**	**β**	**95% CI**	**β**	**95% CI**
Total PA = Inactivity	−3.18	−3.19, −3.17	−1		−1	
Inactivity = MVPA	−0.25	−0.25, −0.24	−1.85	−1.89, −1.82	−1.85	−1.89, −1.82
LPA = MVPA	0.38	0.36, 0.39	0.85	0.82, 0.89	0.85	0.82, 0.89

Abbreviations: LPA- light physical activity; MET- metabolic equivalent; MVPA- moderate-to-vigorous physical activity; Total PA- total physical activity; 95% CI- 95% confidence interval

[*] $P < 0.01$ for all associations

[a] Linear mixed model: Dependent Variable = Independent Variable + Monitored time + Day of week + Sample + Race/ethnicity + (Field center + School within field center + Girl within school within field center included as random effects).

[b] Linear mixed model: Dependent Variable = Independent Variable + Day of week + Sample + Race/ethnicity + (Field center + School within field center + Girl within school within field center included as random effects).

Table 4

Associations Between Selected Physical Activity Measures for Analyses Comparing Variables on the Following Day in Selected 8th Grade TAAG Participants, 2005-2006*.

	MET-minutes[a]		Minutes[a]		% of Monitored Time[b]	
	β	95% CI	β	95% CI	β	95% CI
Total PA $_{Day\ 2}$ = Inactivity $_{Day\ 1}$	−0.80	−0.84, −0.76	−0.28	−0.29, −0.26	−0.22	−0.23, −0.21
Inactivity $_{Day\ 2}$ = MVPA $_{Day\ 1}$	−0.05	−0.06, −0.04	−0.37	−0.43, −0.31	−0.11	−0.15, −0.07
LPA $_{Day\ 2}$ = MVPA $_{Day\ 1}$	0.03	0.02, 0.05	0.06	0.01, 0.10	0.05	0.01, 0.09
MVPA$_{Day\ 2}$ = MVPA$_{Day\ 1}$	0.24	0.23, 0.25	0.24	0.23, 0.25	0.22	0.21, 0.23

Abbreviations: LPA- light physical activity; MET- metabolic equivalent; MVPA- moderate-to-vigorous physical activity; Total PA- total physical activity; 95% CI- 95% confidence interval

[*] $P < 0.01$ for all associations

[a] Linear mixed model: Dependent Variable = Independent Variable + Monitored time + Day of week + Sample + Race/ethnicity + (Field center + School within field center + Girl within school within field center included as random effects).

[b] Linear mixed model: Dependent Variable = Independent Variable + Day of week + Sample + Race/ethnicity + (Field center + School within field center + Girl within school within field center included as random effects).