STUDIES OF THE "ACTIVITYSTAT" HYPOTHESIS

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ABSTRACT

Studies of the “Activitystat” Hypothesis

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This dissertation explored the potential existence of an “activitystat:” a biologically controlled regulatory mechanism for physical activity. This was accomplished through two studies of participants in the Trial of Activity for Adolescent Girls (TAAG). The first study examined the tracking of physical activity over a two-year time period. In the second study we investigated the associations between physical activity and inactivity.

It has been suggested that tracking, or stability, of physical activity levels over time is indication that an “activitystat” exists. That is, despite changes in social and environmental influences on physical activity over time, an individual’s relative rank of physical activity within a group remains consistent. TAAG provided a unique opportunity to examine tracking since it included both an objective and subjective measure of inactivity and physical activity. In 951 participants who were measured in 6^{th} grade and two years later in 8^{th} grade, tracking of inactivity, moderate-to-vigorous physical activity, and vigorous physical activity was fair-to-moderate. Objectively measured tracking tended to be higher than that from self-reported inactivity and physical activity. These results cast some doubt on the “activitystat” hypothesis as they suggest

that physical activity and inactivity habits are dynamic for most girls during early adolescence.

The “activitystat” hypothesis also posits that increases in moderate-to-vigorous physical activity are accompanied by a compensatory reduction in light physical activity and an increase in inactivity in order to maintain a consistent total physical activity level from day to day. In 6,916 8th grade TAAG participants we found no associations over 6 days of measurement between physical activity and inactivity that would suggest compensatory changes occur that would result in the maintenance of total physical activity levels. As girls increased their inactivity total physical activity decreased, as moderate-to-vigorous physical activity increased inactivity decreased, and as moderate-to-vigorous physical activity increased light physical activity increased.

This dissertation failed to find support for the “activitystat” hypothesis. These findings may indicate that well-designed physical activity interventions for adolescent girls should be able to produce positive results through either increasing physical activity or decreasing inactivity.

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LIST OF ABBREVIATIONS

BMI	body mass index
CATCH	Child and Adolescent Trial for Cardiovascular Health
DEXA	dual x-ray absorptiometry
GEE	generalized estimating equation
ICC	intraclass correlation
KCAL	kilocalorie
LPA	light physical activity
MET	metabolic equivalents of task
MTI	Manufacturing Technologies Incorporated
MVPA	moderate-to-vigorous physical activity
OR	odds ratio
PA	physical activity
PAHR-50	heart rate 50% above resting level
PE	physical education
SAPAC	self-administered physical activity checklist
SES	socioeconomic status
TAAG	Trial of Activity for Adolescent Girls
TDEE	total daily energy expenditure
TV	television
VPA	vigorous physical activity
3DPAR	3-day physical activity recall
95% CI	95% confidence interval

I. INTRODUCTION

Regular physical activity throughout the lifespan is an important contributor to the prevention of chronic disease (1). However, studies have shown a consistent decline in physical activity with age (2-4) and have indicated that the adolescent years are the period of life with the greatest rate of decline in physical activity levels (2). This decline in physical activity presents an obstacle to current recommendations that encourage adolescents to participate in moderate-to-vigorous intensity physical activity (MVPA) 60 minutes per day (5).

A strategy commonly used in physical activity interventions to increase physical activity is to add opportunities for activity or increase the duration or intensity of activity (6-9). Decreasing time spent inactive has also been used as a method to increase physical activity (10-12). Increased time spent inactive has been suggested to be a primary factor contributing to reductions in physical activity and increases in obesity in adolescents (13). Inactivity requires little to no extra energy above that of resting levels and may reduce the time spent being physically active. If time spent inactive replaces physical activity then an inverse relationship between inactivity and MVPA or vigorous physical activity (VPA) would be expected. However, data to support the relationship between inactivity and MVPA are equivocal (11, 12, 14, 15). These findings suggest that a better understanding of the relationship between inactivity and the components of total physical activity (time spent in light physical activity and MVPA) is needed.

It has been hypothesized that energy expenditure is physiologically regulated and that each individual has his/her own set-point for physical activity (16, 17). It is thought that individuals may compensate for high amounts of physical activity by lowering activity at a later time in order to maintain energy balance. Existence of such a biologically controlled compensatory phenomenon may help explain the lack of a relationship between inactivity and MVPA or VPA seen in some studies and may potentially hinder the success of interventions aimed at increasing physical activity. If physical activity level is a tightly regulated biological process, then a rethinking of current intervention strategies may be necessary.

A recent study (17) has suggested that a high correlation of physical activity levels from one-year to the next within an individual is evidence of an “activitystat,” a biologically controlled regulatory mechanism for physical activity. That is, despite changes in social and environmental influences on physical activity over time, an individuals relative rank of physical activity within a group remains consistent. This phenomenon is commonly called tracking of physical activity. A number of studies have investigated how well physical activity tracks over a period of time in youth (18-24) and have generally found that tracking of physical activity between multiple time points is low to moderate at best. Most of these studies have relied on subjective self-report measures of physical activity, which may account for the low correlations, and have used crude correlations unadjusted for any covariate effects. Studies of tracking of physical activity that use more accurate objective measures of physical activity and more sophisticated statistical methods are needed and may shed some light on the existence of an “activitystat.” Tracking studies that rely on accelerometry may also provide needed information related to the stability of physical activity behaviors in adolescents and potentially identify individuals at risk for obesity and cardiovascular disease early enough to confer benefits from preventive measures.

This dissertation investigated the possible existence of an “activitystat” in adolescent girls through two supportive studies. First, we examined the tracking of physical activity behaviors over a 2-year period. Second, we examined the associations between physical activity intensities and total physical activity over 6 days in middle-school girls. Physical activity research has largely relied upon self-report methods for the measurement of physical activity and inactivity.

Previous tracking studies have found inconsistent results and studies of the association between inactivity and the components of total physical activity have found only very small and frequently insignificant relationships in the hypothesized direction for these variables. This may be a result of using less accurate and reliable methods of measurement. In this dissertation we were able to measure both physical activity and inactivity objectively via accelerometry using population specific, validated intensity of activity thresholds.

II. SPECIFIC AIMS

A. Aim 1:

Aim 1 examined the tracking of inactivity, MVPA, and VPA. A high correlation of inactivity or physical activity levels from one-year to the next within an individual may be evidence of a biologically controlled regulatory mechanism for physical activity. That is, despite changes in social and environmental influences on physical activity over time, an individual's relative rank of physical activity within a group remains consistent.

Assess the tracking of inactivity, MVPA, and VPA over a two-year period as measured by accelerometry and self-report.

<u>Aim 1a:</u> Examine the association between accelerometer measured and self-reported inactivity, MVPA, and VPA assessed at baseline and follow-up.

We hypothesize that the intraclass correlation and kappa statistic will be higher for inactivity than for MVPA or VPA. The intraclass correlations and kappa statistics will be higher for accelerometer measured inactivity and MVPA than for self-reported inactivity and MVPA.

<u>Aim 1b:</u> For both accelerometry measured and self-reported inactivity, MVPA, and VPA determine the odds of being in a given quintile at follow-up given that an individual was in that same quintile at baseline.

We hypothesize that for both accelerometry and self-report, the odds of being in a given quintile of inactivity, MVPA, and VPA at follow-up will be greater for those in the same quintile at baseline relative to those in any other quintile at baseline.

B. Aim 2:

Aim 2 examined the associations between inactivity and the components of total physical activity. If physical activity is a tightly regulated biological process it would be apparent within these relationships. An individual's total amount of physical activity (all non-sedentary activity) should not be affected by their inactivity level. That is, limiting or increasing an individual's opportunities for physical activity will not affect their total physical activity as an "activitystat" would compensate for the periods of inactivity by increasing activity during the rest of the day in order to reach their set- point for physical activity. Existence of an "activitystat" would result in time spent in moderate or vigorous activity being offset by increases in inactivity. Likewise, periods of high MVPA or VPA would be offset by a reduction in the intensity of light activity. These relationships were examined using two approaches: 1) within the same day; and 2) whether a physical activity intensity exposure on one day affected total physical activity or another physical activity on the next day.

Examine the associations between total physical activity and physical activity intensities using accelerometry.

Aim 2a: Describe the association between total daily physical activity and daily inactivity.

We hypothesize that there will be no association between total daily physical activity and daily inactivity on the same day. We hypothesize that inactivity on one day will not affect total physical activity on the following day..

Aim 2b: Determine the association between daily inactivity and daily moderate-to-vigorous physical activity.

We hypothesize that there will be a positive association between daily inactivity and daily vigorous physical activity on the same day. *We hypothesize that MVPA on one day will be positively associated with inactivity on the* following *day.*

Aim 2c: Examine the relationship between daily light physical activity and daily moderate-to-vigorous physical activity.

We hypothesize that there will be an inverse association between daily light physical activity and daily moderate-to-vigorous physical activity We hypothesize that moderate-to-vigorous physical activity on one day will be inversely associated with light physical activity on the following day.

Aim 2d: Examine the relationship between moderate-to-vigorous physical activity on a given day and moderate-to-vigorous physical activity on the following day.

We hypothesize that there will be an inverse association between moderate-to-vigorous physical activity on a given day moderate-to-vigorous physical activity on the following day.

These aims were met through analyses of extant data from the Trial of Activity in Adolescent Girls (TAAG) (7). TAAG was a 2-year intervention designed to reduce the age-related decline in MVPA by 50% in middle school girls. The intervention was a group-randomized trial consisting of 36 middle schools at six field centers across the U.S.

III. REVIEW OF LITERATURE / BACKGROUND

The first aim of this dissertation examined the tracking of physical activity and inactivity levels over a 2-year period. The following sections review the published literature on longitudinal studies of physical activity levels in children and youth.

A. Tracking of physical activity

Wilkin et al. have suggested that a high correlation of physical activity levels from one-year to the next within an individual lends credence to the existence of a biologically controlled regulatory mechanism for physical activity which they termed an "activitystat." The authors postulate that a stable physical activity level over time, in spite of changes in social and environmental influences, is an indication that physical activity levels may be biologically regulated rather than a result of external influences.

While the merits of this hypothesis are debatable, the importance of this type of analysis is not. A number of studies have examined the stability of physical activity levels over time in children and youth. The analysis dealing with this phenomenon is called tracking. Tracking refers to 1) the stability of relative rank or position within a group over time or 2) the predictability of a measurement early in life for the value of the same variables later in life (18). Knowledge of the tracking of physical activity allows the prediction of future activity levels and may potentially identify individuals at risk early enough to implement beneficial interventions.

For the evaluation of tracking, serial measurements must be made on the same individuals over an extended period of time; therefore only longitudinal data may be used. Tracking of physical activity has largely been explored via self-report data. However, a few studies have relied upon more objective measures of physical activity. The following is a summary of these studies.

1. Tracking of physical activity via self-report

McMurray and colleagues (19) evaluated the tracking of physical activity over a 6 year period in a group of youth in grades 3-4 at baseline. Physical activity was measured once per year using a self-report questionnaire. Spearman correlation between annual measures of physical activity ranged from 0.25 to 0.58. Spearman correlations were significantly higher for African-American boys than Caucasian boys, but no differences were seen between African-American girls and Caucasian girls. When subjects were divided into high, moderate, and low categories of PA, the kappa statistics indicated low to moderate agreement on a year-to-year basis, however from the first year of follow-up to the last kappa was very low (0.033 in African-American girls to 0.224 in African-American boys). GEE stability coefficients showed significant tracking of physical activity while indicating that physical activity levels tracked better for boys than girls and slightly better for African-Americans than Caucasians (19).

These results indicate low tracking of physical activity in youth from grades 3-4 through late high school. Correlations from initial measurement to final measurement seven years later were very low suggesting little tracking of physical activity over the years, and the kappa statistics imply considerable movement between high, moderate, and low physical activity groups by individuals, while the GEE coefficients were moderate for boys (~0.5), but less so for girls (~0.40). Such low correlations could be due to the use of self-report questionnaire which tend to have considerable variability or due to the relatively long follow-up period (as follow-up time increases tracking coefficients decrease). This study is the first to find differences in tracking by ethnicity, indicating that more African-Americans maintained their physical activity levels over the course of the study than Caucasians. The authors conclude that low tracking of physical activity may suggest that change of physical activity levels is possible in youth and that interventions should target youth in order to produce healthy physical activity habits at a young age (19).

Janz and colleagues (20) examined the tracking of physical activity in a group of children ages 7 -12 at baseline over a 5 year period. Physical activity was measured in 2 ways in this study: 1) inactivity was captured using a 1-day recall of time spent watching TV and playing video games and 2) time spent in vigorous activity was captured using a 3-day recall of the number of bouts children spent in activity that made them sweat or breathe hard.

In general, there was a decline in the Spearman rank correlations the further from baseline a measure was taken, however tracking of physical activity was moderate in boys and girls for vigorous PA, moderate in boys for inactivity, and tracking was low for girls in inactivity over the 5 years of study. Correlations for vigorous activity ranged from 0.52 for year 4 to year 5 to 0.32 for year 1 to year 5 in boys and from 0.65 for year 4 to year 5 to 0.43 for year 1 to year 5 in girls. For inactivity, correlations ranged from 0.56 for year 4 to year 5 to 0.48 for year 1 to year 5 in boys and from 0.59 for year 4 to year 5 to 0.16 for year 1 to year 5 in girls. These results suggest that sedentary behaviors are established earlier in boys than in girls and may be resistant to change, thus interventions to reduce TV watching and video gaming, particularly in young boys, may be justified (20).

Andersen and Haraldsdottir (24) have also demonstrated poor tracking of physical activity in a group of youth ages 16-19 years at baseline who were followed for 8 years. The Pearson correlation coefficient between baseline and follow-up for PA, assessed via questionnaire, was 0.31 for males and 0.20 for females. In addition, the percentage of men staying in the upper quintile of physical activity (lowest levels of PA) from baseline to follow-up was 53%, while in women only 8% stayed in the upper quintile. This suggests that men who were sedentary as late teenagers remained sedentary 8 years later, while women who were sedentary as late teenagers managed to increase their physical activity levels over the subsequent 8 years. These results suggest that, particularly in males, early intervention to promote healthy physical activity habits should start prior to the late teenage years (24).

Tracking of physical activity has also been assessed in a group of Finnish youth by Raitakari and colleagues (23), who measured physical activity via questionnaire, in adolescents ages 12, 15, and 18 years at baseline and followed for 6 years. Significant tracking of physical activity was observed with 3-year correlations ranging from 0.35 to 0.54 in boys and from 0.33 to 0.39 in girls. Six-year correlations ranged from 0.18 to 0.43 and 0.17 to 0.37 in girls. The correlations were higher in the older age groups. Based on their physical activity levels at baseline the youth were classified as either sedentary or active. At follow-up, 57% of those classified as sedentary at baseline remained sedentary, while 44% of those classified as active at baseline remained active. These data indicate that physical inactivity tracks better than physical activity and that the later in adolescents one is, the more likely they are to maintain their physical activity habits (23).

Twisk et al. (22) utilized GEE to assess tracking of physical activity in the Amsterdam Growth and Health Longitudinal Study. Subjects were followed for 15 years, mean age at baseline was 13 years. GEE coefficients for physical activity were modest at 0.34 over the entire 15 year period of study. In addition, subjects were grouped into quartiles of physical activity level at baseline and the odds ratio an individual in the lowest quartile of physical activity at baseline (least amount of PA) was found to be 3.6 times more likely to remain in the lowest quartile after 15 years than those in the upper three quartiles at baseline (22).

In a group of Canadian youth, Fortier and colleagues (18) found the Spearman rank correlations for 11-16 year old boys and girls to be 0.03 to 0.33 over the entire 7 years of follow-up. Physical activity was assessed using a modified version of the Minnesota Leisure Time Activity Questionnaire. As seen in previous studies, the older the age at baseline the higher the tracking of physical activity at the end of follow-up.

2. Tracking of physical activity via objective measures

Pate et al. (21) examined tracking of physical activity in a group of young children, ages 3-4 years at the beginning of the study using heart rate as the measure of physical activity. Follow-up occurred annually for three years. These investigators quantified physical activity as the percentage of minutes between 3:00 PM and 6:00 PM during which heart rate was 50% or more above individual resting heart rate (PAHR-50). PAHR-50 varied little between the 3 years of observation, ranging from 12.8% to 14.8%. Pearson correlations for the 3 years ranged from 0.53-0.63. Spearman correlations ranged from 0.57 to 0.66 indicating that children generally maintained their rank within the distribution of PAHR-50 over the 3 years of follow-up. Intraclass correlations (0.81) and kappa statistics across the 3 years (0.23-0.43) also indicated tracking of physical activity from year to year (21).

The results of this study suggest that physical activity, when measured via heart rate, tends to track in young children; those children that are most active stay active and those children that are less active remain less active than their peers. This study also indicates that interventions designed to promote physical activity in children as young as 3-4 years of age may have beneficial health effects later in life (21).

In the Iowa Bone Development Study (25), accelerometers were used to assess tracking of inactivity and physical activity, while self-report was used to assess TV watching and video game playing over a 3-year period in a group of elementary school aged children. Spearman rank-order correlation coefficients between baseline and follow-up for moderate and vigorous activity were moderate ($r = 0.32$ -0.40). Inactivity as measured by accelerometry had a slightly higher correlation than those found for moderate and vigorous activity ($r=0.41$ for boys and 0.44 for girls). Sedentary behavior as measured by self-report was more stable ($r = 0.37$ to 0.52) than inactivity, with the exception of video playing in boys ($r = 0.18$). These latter results may suggest that specific sedentary behaviors, such as TV watching, are more stable over time than an all encompassing measure of inactivity, such as that measured by accelerometry.

Wilkin et al. (17) assessed tracking of physical activity using accelerometry in elementary school aged children over a one-year period. Total physical activity did not change over one year (37.5 vs 37.4 minutes, P=0.88). Also, the percent of time spent in high-intensity activity did not change over the time period (29.2 vs 31.2%, P=0.08 for girls; 32.9 vs 33.6%, P=0.56 for boys). Moderate correlations for daily activity between years were moderate (r=0.49 total, r=0.36 girls, r=0.55 boys, all P<0.001).

3. Tracking summary

It is important to know whether tracking of physical activity occurs, so that appropriate populations can be targeted for intervention. It is commonly believed that increasing physical activity early in life results in adults who will have higher physical activity levels than they otherwise would have without early intervention. However, most of the studies reviewed here do not agree with this belief. Tracking of physical activity in youth is moderate at best; indicting that increasing physical activity during childhood may not result in more active adults.

Tracking measures are highly influenced by measurement error. Unfortunately, measurement of physical activity is not very precise, particularly when assessed by questionnaire, so it is very plausible that the relatively low tracking of physical activity seen in many paper is at least partly due to the poor methods commonly used to measure physical activity. To date, only a few studies have used an objective measure of physical activity to assess that tracking of physical activity in youth (17, 21, 25, 26). Perhaps not surprisingly, these studies have found the highest levels of tracking of physical activity. More longitudinal studies utilizing objective measurements of PA, such as accelerometry, are needed to help answer questions about tracking of physical activity in youth. Additionally, studies that compare tracking as assessed by both self-report and accelerometry would provide much need information on the ability of self-report to accurately measure this phenomenon.

Finally, a few studies indicate that physical inactivity tracks better than physical activity in youth (20, 25, 26). Additional studies are needed to further explore these findings. Janz et al. (25) found that self-reported TV watching and video game playing tracked to a greater extent than accelerometer measured physical activity and inactivity. Similar analyses using self-reported and objectively measured physical activity and inactivity may help identify behaviors that can be successfully targeted for intervention.

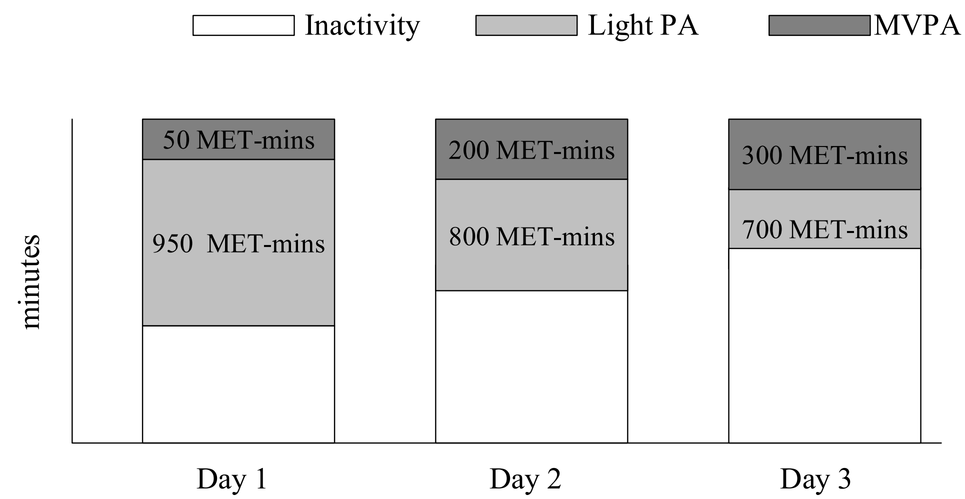
B. Regulation of physical activity

The second aim of this dissertation examined the relationship between intensity of physical activity and total physical activity levels. The following sections review the published literature on the regulation of and potential compensation in physical activity and physical activity intensity patterns in both adults and children.

1. Compensation in Physical Activity

The inconsistent relationship between physical activity intensity patterns maybe due to the occurrence of a compensatory phenomenon, where increases in moderate or vigorous activity are accompanied by a reduction in light activity and an increase in inactivity. Epstein and Wing (27) have suggested that the underwhelming findings of exercise weight loss studies may be a result of changes in other components of the energy balance equation, particularly non-exercise physical activity. As a result of participating in structured exercise, individuals may reduce their normal activities of daily living (non-exercise PA), thus the additional physical activity from exercise may not yield the expected increase in total energy expenditure. Rowland (16) has hypothesized that an "activity center" within the central nervous system controls an individual’s amount of physical activity over time, and therefore daily EE. Rowland suggests that physical activity, just like internal body temperature, pH, and blood pressure, is kept within narrow tolerance limits in order to maintain energy balance. Based on this theory, the “activitystat” would keep total physical activity constant across days by increasing/decreasing the frequency, intensity, and/or duration of time spent in one of the components of total physical activity to compensate for increases/decreases in the other component of total physical activity.

Figure 3.1. 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.



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 3.1 demonstrates how the "activitystat" would maintain a set-point total physical activity level. Total physical activity consists of two components: light physical activity (LPA) and MVPA. In this example, as MVPA increases across the three days, LPA decreases, and total physical activity, expressed in terms of intensity weighted minutes, is unchanged across the three days. 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” compensates for the periods of inactivity by increasing the intensity of activity during the rest of the day in order to maintain the total physical activity set-point.

In both adults and children, there are studies which have investigated the compensation theory. These studies fall into two general types: experimental and observational studies. In experimental studies, physical activity levels are manipulated via exercise training such that they are substantially higher than normal. Energy expenditure or physical activity levels are than compared between the days when exercise occurred and days when no exercise occurred. In one case (28), comparisons were made between days when physical activity levels were restricted (lower than normal) and on a normal activity day. In observational studies, physical activity levels are not altered and comparisons of total physical activity are made between groups of individuals who are thought to have higher MVPA levels and those thought to have less (i.e. those who walk to school versus those who do not). Studies examining compensation in adults have exclusively used experimental study designs, while those in children and youth have used both experimental and observational designs.

Additional evidence of compensation may be found in studies that have examined physical activity intensity patterns. It is commonly believed that as time spent in inactivity increases, the amount of time spent in physical activity decreases. However, studies have failed to find an association between inactivity and activity suggesting that periods of inactivity may be compensated for by periods of high activity. The following sections summarize the evidence for and against the existence of a compensatory phenomenon in physical activity in adults and children, as well as the studies that have examined the relationship between inactivity and total physical activity.

i. Evidence of Compensation in Adults

There are at least two studies which support the compensation theory among elderly adults. Goran and Poehlman (29) demonstrated, in older men, total daily energy expenditure did not change after 8-weeks of endurance training, despite an 10% increase in resting metabolic rate plus the increased energy expenditure due to the training. This was due to a 62% reduction in physical activity outside the training program. It may be that the age of these individuals affected their activity during non-exercise times, but the existence of a compensatory mechanism cannot be ruled out.

In a group of elderly men and women, Meijer and colleagues (30) have shown that participation in an endurance training program results in declines in non-training physical activity (all physical activity outside of training) on days training occurred, such that total physical activity for an entire day is equal on days training occurred and days no training occurred. Subjects in this study participated in exercise training twice per week for 12 weeks. Physical activity was measured by accelerometry in this study. After 12 weeks, total physical activity was similar on training and non-training days. Participants showed a decline in non-training physical activity on training days leading the authors to hypothesize that participants anticipated exercise training and reduced their physical activity before training sessions to save energy and compensate for the increased energy expenditure of the training session. Since training was in the afternoon, the decline in physical activity at week 12 was not attributed to participants being fatigued for the remainder of the day (30).

In another study that suggests compensation may occur, Stubbs et al. (31) demonstrated compensation in energy expenditure for bouts of exercise, in a short-term training study of young men. They studied this theory in a group of young men by measuring energy expenditure during a week of heavy exercise and a week of no exercise. After 7 days of high volume exercise (three 40-minute sessions per day), non-exercise energy expenditure significantly declined 83 kcal/day, while after 7 days of no exercise there was no decline in non-exercise EE. However, the compensatory decline in non-exercise energy expenditure during the training week was not enough to offset exercise energy expenditure, as total energy expenditure was higher during the week of exercise compared to the week of no exercise (4200 kcal vs 2740, respectively) (31).

These three studies suggest that there may be some compensatory responses to exercise. In each of these studies declines in non-exercise physical activity were observed as a result of participation in heavy exercise programs. The results appear to be more pronounced in elderly participants than in younger participants which may indicate that there are age differences in compensatory responses.

ii. Evidence Against Compensation in Adults

While there are some data to suggest compensation for bouts of high MVPA in adults, other studies indicate that compensation does not occur, resulting in greater total energy expenditure in those who are most active. Van Etten et al. (32) found an increase in total daily energy expenditure (TDEE) of about ~9% in men after 18 weeks of weight training. Forty percent of the increase was attributed to the weight training program and the remainder was attributed to measurement error or an underestimation of the energy expenditure due to the training. There was no compensatory decline in the amount of activity acquired outside of the training program (32).

Melanson et al. (33) have demonstrated that 24-hour energy expenditure is significantly elevated after either low or high intensity exercise as compared to days when no activity was performed. Sixteen men and women entered a whole room calorimeter for 24 hours on 3 separate occasions; one day no exercise was performed, one day light intensity exercise was performed, and one day high intensity exercise was performed. The average increase in energy expenditure was 506 ± 34 kcal/day on the light exercise days and 546 ± 34 kcal/day on the heavy exercise days compared to the sedentary days. If compensation for the bouts of activity occurred we would expect there to be no difference in energy expenditure between the three days of measurement.

Meijer and colleagues (34) examined the effect of a 5-month endurance training program on physical activity and TDEE in 16 males and 16 females preparing for a half marathon. Total physical activity, measured using an accelerometer, increased by approximately 62% after 20 weeks of training. Non-exercise physical activity did not change significantly although in males it tended to increase. Average daily metabolic rate increased significantly in males after 20 weeks (~800 kcal /day). Although not statistically significant, this was approximately 15% above the increase in energy expenditure expected from the training alone. In females no significant increase in average daily metabolic rate was found (~300 kcal /day). The authors concluded that there was not a compensatory decline in non-exercise physical activity due to the training program in males or females and in fact exercise increased non-exercise physical activity in males but not in females, possibly due to differences in sympathetic nervous system activation between genders (34).

The fact that the two of the three studies which indicate compensation for high levels of physical activity may exist occur in elderly subjects may be of importance. Perhaps older individual's perceived effort at a given intensity (i.e. 50% of maximal effort) is greater than the perceived effort of younger individuals at the same intensity. This would result in elderly particpants being more fatigued as a result of exercise and potentially needing to rest longer than a younger individual. If true, this may explain why compensation was found in elderly subjects, but not in younger adults. However, we would then expect to not find compensation in children or youth. The next section summarizes the evidence for and against compensation in children and youth.

iii. Evidence of Compensation in Children

Both experimental and observational studies have examined the compensation phenomenon in children and youth with equivocal results. In a recent study, Wilkin et al. (17) made a case for the existence of an "activitystat," a biological feedback loop which regulates physical activity levels. The authors hypothesized that if physical activity were centrally regulated then physical activity levels should be independent of environmental opportunity or environmental intervention. Their hypotheses were tested by comparing accelerometer measured total physical activity levels of different groups of elementary school children in England and Scotland. Wilkins et al. found that there was very little variation in daily physical activity levels of the children. Physical activity remained the same on weekends and weekdays, was not affected by the quantity of school physical education class (PE), or by whether the child walked or drove to school, or how much time was spent awake or in front of a television. All of these findings would suggest that physical activity is biologically regulated and that compensation for periods of high physical activity may occur.

When comparing children who walk to school to those who are driven, it may be expected that the walkers would have greater total physical activity levels than those children driven to school. However, as indicated in the Wilkin et al. study, comparisons of walkers versus drivers have not resulted in the expected findings. Metcalf and colleagues (35) studied this in a group of 5 year olds in the U.K. and found that those who walked to school had significantly higher accelerometer measured activity levels during the trip to and from school, however total activity over the entire day was not different from those who were driven to school suggesting that compensation occurred.

Cooper et al. also examined differences in accelerometer measured physical activity in walkers and drivers to school in 10 year old U.K. children (36). In both boys and girls, the walkers had greater MVPA during the morning commute to school than drivers. However, in girls total daily MVPA and mean accelerometer counts per minute were not different between the two groups, again possibly indicating compensation for a higher volume of physical activity in the morning in those who walked to school. In boys this relationship was not seen. Boys who walked to school had greater total daily MVPA and mean accelerometer counts per minute than those who drove and were more active in the afternoon than those who drove to school leading the authors to conclude that walking to school may prompt boys to be more active after school, but not girls.

The Child and Adolescent Trial for Cardiovascular Health (CATCH) study (6) may also provide evidence that compensation for physical activity occurs in youth. In this 3-year controlled field trial an intervention was developed that included a physical education component that aimed to increase the amount of MVPA in PE class. At the end of the trial, PE class MVPA, as measured by direct observation, had increased in the intervention schools compared to controls. In addition, self-reported vigorous physical activity was significantly higher in the intervention schools compared to controls by approximately 12 minutes per day. Since PE class MVPA and daily vigorous physical activity increased in intervention schools one would expect that total physical activity would be greater in intervention schools than in controls. However, self-reported total minutes of daily physical activity were not significantly different between intervention and control schools, in fact intervention schools had lower total minutes of physical activity (intervention mean= 145.5 minutes/day vs. control mean= 154.8 minutes/day) suggesting that compensation may have occurred. These findings may be influenced by the unreliability of using self-reported physical activity in children more so than indicating compensation in energy expenditure due to the intervention.

An additional study suggestive of compensator changes in physical activity in children found that adding 5 hours/week of PE to school curriculum resulted in a small decrease in weekday leisure activity, but the difference was not statistically significant (37). The authors noted that the findings may be due to a possible existence of a biological mechanism limiting total daily physical activity.

iv. Evidence Against Compensation in Children

Not all studies that have investigated compensation in youth agree with the reviewed findings. Dale et al. (28) 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. The investigators found no compensatory increases in physical activity in those who had restricted activity during the day. In fact, they found those children who had no restrictions during PE had higher activity levels after school than the children who had restricted activity (28).

Blaak and colleagues (38) found a 12% increase in total daily energy expenditure (measured via doubly-labeled water) in a group of obese 10-11 year old boys who had participated in a 4 week cardiovascular training program. Fifty percent of the increase in daily energy expenditure was attributed to the energy cost of the training program and the other 50% was explained by an increase in energy expenditure outside of training. Thus there was an increase in non-exercise physical activity during the remainder of the day as measured by heart rate telemetry (38).

2. Associations between inactivity and physical activity

It has been suggested that the relationship between inactivity, particularly television viewing, and obesity may be a result of a reduction in energy expenditure due to the displacement of physical activity (13). However, data on the association between inactivity and total physical activity in youth are lacking. In a study of 6^{th} and 7^{th} grade girls in northern California, a negative, but weak, association was observed cross-sectionally between baseline hours of after-school television viewing and level of physical activity. Conversely, after-school television viewing was not significantly associated with change in level of physical activity at follow-up 24 months later (12). Parental report of children's (3-8 years) weekly television viewing hours was significantly correlated with children's caloric intake, but was not associated with children's physical activities (39). Katzmarzyk and collegues (15) found the correlation between time watching television and estimated energy expenditure and MVPA were low (−0.03 to −0.15) and not significant in Quebec youth. Those in the lowest and highest quartiles of television showed no consistent significant differences in energy expenditure or MVPA. Using data from NHANES III, Crespo et al. (14) found an inverse association between daily bouts of physical activity and daily hours of TV viewing in both boys and girls. It should be noted that each of these studies assessed physical activity via self-report. The possibility that error associated with self-report influenced the outcome of these studies cannot be ruled out. Studies using objective measures of physical activity are needed to corroborate these findings based on self-report of the relationship between physical activity intensity patterns.

3. Regulation of physical activity summary

Methodological differences between studies may influence the inconsistent findings of these studies. Doubly labeled water, accelerometry, heart rate telemetry, and self-report have all been used to measure physical activity which may account for the differing results of these studies. In youth, observational studies provide the best evidence that compensation may occur, while experimental studies have found to the contrary. In observational studies, participants take part in their "normal" activity levels, while in the experimental studies activity levels tend to be increased considerably above "normal." It may be that there is a threshold of total physical activity above which there are no compensatory changes in inactivity in youth. That is, youth may need to considerably exceed their typical activity levels in order to prevent compensatory changes in inactivity. Differences in the intensity of physical activity or exercise performed by subjects may also contribute to the inconsistencies seen between experimental and observational studies in youth. It is possible that only vigorous activity results in compensatory increases in inactivity, while moderate activity is not associated with compensation. Age may also play a role in whether or not compensation for physical activity occurs as several studies in elderly populations have demonstrated compensatory physical activity patterns.

Existence of a biologically controlled compensatory phenomenon in physical activity may require a rethinking of physical activity interventions. Currently, interventions are largely focused on increasing opportunities for youth to be active. Compensation would limit, if not negate, the impact increased opportunities for physical activity may have. If there is a threshold for total physical activity above which compensation does not occur then interventions may need to target greater increases in physical activity levels than they currently are. However, few studies have examined whether or not compensation in physical activity occurs in youth. Further research is needed, particularly in adolescents, to determine if compensation occurs so that physical activity interventions may be developed accordingly.

IV. Research Design and Methods

All analyses relied on data collected in the Trial for Activity in 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 (7). TAAG has six field centers (at the Universities of Arizona, Maryland, Minnesota, and South Carolina; San Diego State University; and Tulane University), a Coordinating Center (at the University of North Carolina, Chapel Hill) and a Project Office at the National Heart Lung and Blood Institute.

The TAAG study design employed two cross-sectional samples, one drawn from 6th graders at the beginning of the study in the spring of 2003 and the second drawn from 8th graders in the spring of 2005 following the 2-year implementation of the intervention. Additionally, a second post-treatment follow-up assessment was collected in 8th grade students within the same schools one year after the active intervention phase ended (spring 2006). The purpose of the second 8^{th} grade sample was to evaluate the sustainability of the TAAG intervention in the schools in which it was delivered.

A. TAAG Study Population

In the 6^{th} grade sample of girls, consent was obtained from 1721 girls; of these girls, 1576 (92%) had complete physical activity, anthropometric, and demographic information. Among girls in the 2005 8^{th} grade cross-sectional sample, consent was obtained from 3,504 eligible girls, with 3,440 (98%) having complete measures. Among girls in the 2006 8th grade cross-sectional sample, consent was obtained from 3,853 eligible girls, with 3,476 (90%) having complete measures.

Analyses in Aim 1 were conducted using an adventitious cohort of all girls who had been measured in 6th grade in 2003 and who attended a TAAG school in the spring of 2005. Of the 1,576 girls assessed in the 6th grade, 1,285 were also assessed in the 2005 sample. Among those girls 301 had incomplete or missing physical activity data. Thus, 984 girls provided data these analyses. Analyses for Aim 2 used the 6,916 girls with complete data from the 2005 and 2006 8th grade samples.

Table 4.1. Descriptive information (mean, SD) on 6th and 8th grade girls in the TAAG study.

	Cross-sectional Samples			Longitudinal Sample	
	6th grade (n=1,576)	8th grade 2005 (n=3,440)	8th grade 2006 (n=3,476)	6th grade (n=984)	8th grade 2005 (n=984)
Age (yrs)	12.0, 0.5	13.9, 0.5	14.0, 0.5	11.9, 0.4	13.9, 0.4
Height (cm)	152.5, 7.5	160.1, 6.6	159.7, 6.5	152.2, 7.7	160.3, 6.6
Weight (kg)	48.9, 14.0	58.7, 15.3	58.3, 15.2	48.4, 13.8	58.2, 15.0
BMI (kg/m^2)	20.9, 4.9	22.8, 5.3	22.8, 5.4	20.7, 4.7	22.6, 5.2
% Body Fat	28.0, 9.3	31.5, 8.4	31.4, 8.5	27.9, 9.1	31.3, 8.3
Min. MVPA (mins.)	23.7, 11.7	22.2, 11.2	21.7, 11.3	23.5, 11.6	22.0, 10.8

B. Measurements and Protocols

1. Measurement of Physical Activity

i. Measurement via accelerometry

Physical activity was measured using the MTI ActiGraph accelerometer model 7164 (Manufacturing Technologies Inc., Fort Walton Beach, Florida). The ActiGraph is a uniaxial accelerometer that measures acceleration caused by body movement in the vertical plane. It is small and lightweight and capable of measuring and storing temporal patterns of activity over user-defined intervals (ranging from 1 second to several minutes) over a period of days or weeks. Raw output from the ActiGraph is generally expressed as counts. The quantity and quality of activity may be assessed using the total counts and number of counts per time interval, respectively. The ActiGraph has been validated in children, most commonly against oxygen consumption and heart rate telemetry (40-45), however direct observation (46) and doubly labeled (47) water have also been used as criterion measures.

Prior to implementing the intervention, TAAG investigators undertook a population specific calibration study of the ActiGraph to define accelerometer count thresholds to categorize sedentary, light, moderate, and vigorous activity in middle school girls (48). Activities performed by the girls were divided into intensity categories based on expert opinion. A range of accelerometer counts were considered as candidate cut-points for defining intensity levels. Counts observed for low intensity activities that exceeded a given threshold were classified as false positives, and counts observed for moderate or higher intensity activities that fell below the same threshold were classified as false negatives. Activity thresholds were defined by minimizing the false positive and false negative classifications. Thresholds ranges of 0- 2.09, 2.1- 4.59, 4.6- 6.49, and ≥ 6.5 METs gave the lowest number of false positive and false negative classifications for sedentary, light, moderate and vigorous activity, respectively. These MET ranges correspond to accelerometer count ranges of 0-50, 51-1499, 1500-2600, and > 2600 for sedentary, light, moderate and vigorous activity, respectively.

ActiGraph Protocol

The ActiGraph measurement required at least seven days and two school visits for each participant. Girls were asked to wear the accelerometer on a belt around their waist over their right hip, except when they were sleeping, bathing, or swimming. ActiGraphs were initialized to begin data collection at 5:00 AM the day after they were distributed to girls (giving 6 complete days of recorded activity), and the epoch of integration was set at 30 seconds.

Imputation of missing ActiGraph data

A challenge when dealing with accelerometer data is the occurrence of missing data due to noncompliance with study protocols. Removal of the monitor can lead to individuals contributing differing amounts of data, which may potentially bias study results. TAAG investigators tested the effectiveness of imputation methods to reduce bias resulting from missing accelerometer data in their study (49). In a simulation experiment, the investigators deleted accelerometer count data for an entire day, or a segment of the day at random or in a systematic fashion such that those at upper levels of BMI and lower levels of physical activity were more likely to have missing data. Data were imputed for those who had nonmissing counts over less than 80% of a standard measurement day, which was defined as the period of the day during which at least 70% of participants were wearing the monitor. Estimates of activity computed from the observed data and those based on a data set in which the missing data were imputed were equally unbiased in the data that were deleted at random, but the imputed estimates were more precise. In the systematically deleted data, the bias in estimated activity was lower using imputation procedures. Based on these results the authors concluded that imputed estimates of activity are more precise and less biased than those derived from an observed data analysis approach when sporadic missing data are present (49).

Because the ActiGraph records even slight motion as a non-zero count, a sustained 20-minute period of zero counts was considered a non-wearing period, and missing data were imputed using the methods described above. On average, 12 hours of data over 6 days of ActiGraph measurement are missing per girl. Both a raw data set containing the observed accelerometry data and a data set consisting of imputed data to replace missing accelerometry data exist. The proposed analyses will be conducted using both the raw and imputed data to examine the influence of imputation on the observed associations.

ii. Measurement via self-report

The 3-Day Physical Activity Recall (3DPAR) is a self report instrument that captures physical activity information by asking subjects to recall activity performed over the previous 3 days (50). Respondents recall their past physical activity behavior from each of the three previous days, beginning with the most recent day. To help recall activities more accurately, each day is segmented into 34, 30-minute time blocks from 6 a.m. until midnight. The 3DPAR provides a numbered list of commonly performed activities grouped into categories such as eating, work, after-school, physical activities, etc. For each 30-minute time block, respondents are instructed to record the number corresponding to the main activity they performed during that time interval.

The 3DPAR has been found to be a valid measure of physical activity in 8^{th} and 9^{th} grade girls (50). Pate and colleagues have demonstrated that self-reported total daily METs ($r=0.46$, $p<0.001$)), 30-minute blocks of moderate to vigorous physical activity

($r=0.27$, $p<0.05$), and 30-minute blocks of vigorous activity ($r=0.41$, $p<0.001$) were all significantly correlated with related measures from accelerometry(50). TAAG investigators (42) assessed the reliability and validity of the 3DPAR and a second physical activity recall instrument (SAPAC) using accelerometry as the criterion measure in a group of middle school grade boys and girls. The 3DPAR was found to have high test-retest reliability for both MVPA and vigorous physical activity (r=0.67 and 0.83, respectively). Correlations between accelerometry and the 3DPAR were modest at best for both MVPA and vigorous activity (r=0.28 and 0.16, respectively), but comparable to those found in other studies comparing self-report to accelerometry (45, 51). These results suggest that the 3DPAR is a useful tool for assessing physical activity in adolescents.

3DPAR protocol

The 3DPAR was administered in a group setting during one class period using a paper and pencil format. Each day is divided into thirty-four 30-minute time blocks (data is only recorded from 7AM to midnight). Subjects are provided a list of common activities grouped into the following categories: sleep/bathing, eating, work, after-school/spare time/hobbies, transportation, and physical activities/sports. Each activity has a unique code. For each 30-minute time period subject's write in the code of the main activity performed during that period. If more than one activity was performed, only the activity performed the most is recorded.

For non-sedentary activities recorded, subjects are asked to rate the intensity of each activity performed as light, moderate, hard, or very hard. Illustrations of individuals performing an activity at each of the four intensities are provided to help subjects select the proper intensity. To quantify activity for a day, a metabolic equivalent (MET) value corresponding to each level of intensity is assigned to each 30-minute block (52). Assigned MET levels can be used to determine the number of 30-min blocks spent in various intensities of physical activity.

2. TAAG variables

i. Demographic variables

Age is calculated as the difference between the child's birth date and the date of measurement. As part of the Student Questionnaire, which all girls completed, race/ethnicity was indicated on a checklist which included (1) Caucasian (White, non-Hispanic), (2) Black, (3) Hispanic, (4) Asian/Pacific Islander, (5) American Indian, and (6) Other. Race/ethnicity will be coded as a 6 level categorical variable. Participants were asked to check as many categories as apply. If preliminary analyses indicate that collapsing race/ethnicity categories is appropriate, the number of categories may be reduced. A proxy measure of socio-economic status (SES) was assessed at the school level by obtaining the proportion of students who received free or reduced lunch. SES will be a continuous variable with individual school level proportions included in the models.

ii. Anthropometric Variables

Subject's body mass was measured while wearing light clothing by use of a balance beam scale. Height was assessed without shoes using a portable stadiometer. Body Mass

Index (BMI) was calculated as weight in kilograms divided by height in meters squared. BMI will be examined as both a continuous and categorical variable. As a categorical variable BMI will have three levels; normal weight, at-risk for overweight, and overweight. These will be defined as a BMI less than the CDC-defined 85th percentile for age and gender, a BMI greater than or equal to the CDC-defined 85th percentile and less than the 95th percentile, and a BMI greater than or equal to the CDC-defined 95th percentile for age and gender, respectively.

Percent body fat was estimated from anthropometric measures using an equation that was developed by TAAG investigators for use in middle school girls: percent fat = -23.39 + 2.27 (BMI) + 1.94 (triceps skinfold, mm) – 2.95 (race, 1 if African American, else 0) – 0.52(Age, yrs) – 0.06(BMI x triceps skinfold, mm). The equation was shown to have an R^2 of 0.88 for predicting percent body fat against the same measure obtained from DEXA (53).

3. Covariates

Potential covariates explored in both Aim 1 and 2 were BMI, percent body fat, age, race/ethnicity, SES, and day of the week (weekday versus weekend). Additionally, in Aim 2) the number of hours the accelerometer was worn per day (centered at 14 hours), the cross-sectional sample (2005 or 2006) from which the girls was drawn, and the day of the week (Monday, Tuesday, …) were examined as covariates.

4. Data acquisition, examination and description

The data from TAAG have already been subjected to extensive cleaning. Frequency distributions of the variables used in each analysis were examined in exploratory. Descriptive characteristics of the participants and correlations between the outcomes, exposures, and covariates were summarized.

5. Statistical Methods

The TAAG data are hierarchical in nature, with girls nested within schools, and schools nested within field centers. Influences of the shared social and geographic environment make it likely that two girls in the same school are more alike than girls from different schools. This suggests that responses for girls within a school will be correlated, invalidating the assumption of standard ordinary least squares models that observations are independent. There is an expectation for a positive intraclass correlation reflecting an extra component of variance attributable to the group. This extra variation increases the variance of any group-level statistic. Moreover, the degrees of freedom available to estimate group-level statistics are limited by the number of groups in each condition. Any test that ignores either the extra variation or the limited degrees of freedom has a Type I error rate that is inflated (54, 55). In order to account for the extra variation that occurs, mixed model analyses will be used. In all models field center and school within field center will be treated as random effects, while all covariates will be treated as fixed effects. In Aim 2 we also have day nested within girl, therefore girl within school within field center will also be treated as a random effect in each model for this aim.

C. Specific Analyses

1. Analysis plan- Aim 1

For the 3DPAR, inactivity, MVPA, and VPA levels were calculated by summing the number of blocks (30-min segments) of inactivity, MVPA, or VPA reported each day and averaging over the three days of measurement. Inactivity was defined as activities with a MET value less than 2 METs, while MVPA will be defined as activities greater than 4.5 METs, and VPA was defined as any activities greater than 6.4 METs.

For accelerometer measured activity, the mean number of minutes per day spent in inactivity, MVPA, and VPA were obtained for baseline and follow-up by summing the 30-second intervals that had values within the intensity thresholds established by Treuth et al. (48) as described above (0-50, 51-1499, 1500-2600, and > 2600 counts per 30-second interval, respectively) and dividing by 2 (one minute = two 30-second intervals). Two averages were calculated: one using all 6 days measured and another limited to the same 3 days that were assessed using the 3DPAR.

At the completion of the 6-day ActiGraph monitoring period, participants completed the 3DPAR. This protocol resulted in having data from both self-report and ActiGraph on three corresponding days, as well as ActiGraph data on 6-days, which included the 3 days that were captured by self-report.

i. Analyses for Aim 1a

Aim 1a examined the association between 3- and 6-day accelerometer measured and self-reported inactivity, MVPA and VPA assessed at baseline and follow-up. Intraclass correlations (ICC) between baseline and follow-up for ActiGraph measured and self-reported physical activity were calculated using the method described by Fleiss and Shrout (56). We use σ_b^2 to represent the variance in physical activity between girls, and σ_w^2 to represent the variance in physical activity within a girl. The ICC is defined as:

$$ICC = \frac{\sigma_b^2}{\sigma_b^2 + \sigma_w^2}$$

Differences in the ICCs from the ActiGraph (both 3- and 6-day) and 3DPAR were assessed using the method described by Steiger (57) to compare correlations drawn from the same sample.

Kappa statistics were calculated to assess the agreement in inactivity, MVPA, and VPA at baseline and follow-up for both 3- and 6-day ActiGraph measured and self-reported physical activity. In order to calculate the kappa statistics ActiGraph and self-reported activity were categorized into quintiles of the population distributions. Kappa statistics were then calculated using the following formula (58):

$$Kappa = \frac{P_o - P_e}{1 - P_e}$$

where P_o is the observed agreement between baseline and follow-up and P_e is the expected agreement between baseline and follow-up. Differences in the kappa statistics from the ActiGraph (both 3- and 6-day) and 3DPAR were assessed using the method described by McKenzie (59) to compare kappas drawn from the same sample.

ii. Analyses for Aim 1b

For 3- and 6-day accelerometry measured and self-reported inactivity, MVPA, and VPA, Aim 1b determined the odds of being in a specific quintile at follow-up given assignment in the same quintile at baseline relative to being in any other quintile at baseline.

Girls were categorized into quintiles based on their location within the distribution of inactivity, MVPA, and VPA. Dichotomous variables were created for each baseline and follow-up quintile and coded as 1 or 0 depending on whether a girl's baseline inactivity, MVPA, or VPA fell into a given quintile or fell into one of the other four quintiles.

Data were analyzed with a logistic mixed model using PROC GLIMMIX in SAS. The univariate association as well as the multivariate association with covariates of interest were tested.

As an example, the multivariate logistic mixed model examining the odds of being in the highest quintile of MVPA (most MVPA) at follow-up takes the form of:

$$\text{logit}\,[Y_{ijk}] = \beta_{0jk} + \beta_1 x_{1ijk} + \sum_{p=2}^{n} \beta_p x_{pijk} + u_{0jk} + u_{00k} + e_{ijk}$$

Where:

Y_{ijk} =odds of being in highest quintile of MVPA (most MVPA) at follow-up for girl *i* in school *j* and site *k*

β_{0jk}=background odds of being in highest quintile of MVPA at follow-up in school *j* and site *k*

β_1= coefficient for the effect of being in highest quintile of MVPA at baseline

X_{1ijk} =in highest quintile of MVPA at baseline (coded as 1 or 0) for girl *i* in school *j* and site *k*

βp= coefficient for the effect of pth covariate on odds of being in highest quintile of MVPA at follow-up

X_{pijk} = *p*th covariate from covariate vector consisting of race/ethnicity, BMI, percent body fat, SES, age, and intervention assignment (treatment or control)

u_{0jk} = random school within site effect

u_{00k} = random site effect

e_{ijk} = random girl within school within site effect

Analyses for each of the five quintiles for 3- and 6-day accelerometry and self-reported inactivity, MVPA, and VPA followed the same form as the example above.

2. Analysis plan- Aim 2

Outcome and exposure variables were derived from ActiGraph data. Time spent within each physical activity intensity were quantified in absolute, relative, and intensity weighted terms. The absolute number of daily minutes (for each of the six days the ActiGraph was worn) spent in inactivity, light physical activity, MVPA, and VPA were calculated by summing the 30-second intervals that had values within the intensity thresholds established by Treuth et al. (48) as described above (0-50, 51-1499, 1500-2600, and > 2600 counts per 30-second interval, respectively) and dividing by 2 (one minute = two 30-second intervals). The relative time spent at an intensity of activity was calculated by dividing the number of minutes spent at a given intensity by the total number of minutes the ActiGraph was worn over the day. Intensity weighted minutes were expressed in metabolic equivalent of task (MET)-minutes. One MET is equivalent to the energy expenditure associated with sitting quietly, while 10 METs is the equivalent of a task that requires 10 times the energy expenditure of sitting quietly (52). Hence, 10 MET-minutes is performing a 10 MET activity for 1 minute or a 1 MET activity for 10 minutes or some other combination of time and intensity that equals 10. MET minutes were calculated by summing the MET value of each 30-second interval within each intensity threshold and dividing by 2 (to convert 30 second intervals to minutes). Since inactivity is assumed to have a MET value of 1, absolute minutes of inactivity and MET-weighted minutes of inactivity have the same value. Therefore inactivity was only expressed in absolute minutes and in relative terms.

Total physical activity was defined as all activity above the inactive threshold (50 counts/30 second epoch). Total physical activity was also quantified in absolute, relative, and intensity weighted terms. Absolute minutes of total physical activity was defined as the sum of all minutes spent in light, moderate, and vigorous activity. The relative total physical activity was defined as the minutes of total physical activity divided by the total number of minutes the ActiGraph was worn over the day. Intensity weighted total physical activity was defined as the sum of the MET values for all 30 second intervals above the inactive threshold divided by 2.

These analyses took a within-subject approach to examine the relationships between inactivity, light physical activity (LPA), moderate-to-vigorous physical activity (MVPA), and total physical activity over 6 consecutive days. The goal of these analyses was to determine if relationships exist between total physical activity and physical activity intensity patterns that are suggestive of compensatory changes that would result in total physical activity levels being maintained from one day to the next. Specific questions addressed included: 1) does total daily physical activity vary as a result of the amount of inactivity on a given day; 2) does daily inactivity vary as a result of the amount of MVPA on a given day; and 3) does daily LPA vary as a result of the amount of MVPA on a given day.

We also explored whether there was a one day time lag in any compensatory relationships between total physical activity and physical activity intensity patterns. To do this we repeated the same analyses as above, however the independent variable was from a given day while the dependent variable was from the following day. For example, we examined whether inactivity on Monday was predictive of total physical activity on Tuesday. Additionally, we examined the relationship between MVPA on a given day and MVPA on the following day to explore whether a 24-hour compensatory relationship existed for MVPA.

i. Analyses for Aim 2a

Aim 2a examined whether inactivity on a given day is predictive of total physical activity on the same day or whether inactivity on a given day is predictive of total physical activity on the following day. The primary outcome was total daily physical activity, while the exposure was daily inactivity. Three separate analyses were conducted with total daily physical activity and inactivity concurrently expressed in either absolute, relative, or intensity weighted terms (equivalent to absolute minutes for inactivity).

Data were analyzed using the general linear mixed model using PROC MIXED in SAS. The univariate association between total daily physical activity and daily inactivity as well as the multivariate association with covariates of interest were tested.

The multivariate mixed model takes the form of:

$$Y_{hijk} = \beta_{0ijk} + \beta_1 x_{1hijk} + \sum_{p=2}^{n} \beta_p x_{phijk} + u_{0ijk} + u_{00jk} + u_{000k} + e_{hijk}$$

Where:

Y_{hijk} = total physical activity on day *h* (or *h*+1 for following day analysis) for girl *i* in school *j* and field center *k*

β0ijk=mean total physical activity for girl *i* in school *j* and field center *k*

β1= coefficient for the effect of inactivity on total physical activity

X_{1hijk} = inactivity on day *h* for girl *i* in school *j* and field center *k*

βp= coefficient for the effect of *p*th covariate on total physical activity

X_{phijk} = *p*th covariate from covariate vector consisting of race/ethnicity, BMI, percent body fat, SES, age, day of week, sample (2005 or 2006), hours monitor was worn

u_{0jk} = random girl within school within field center effect

u_{00jk} = random school within field center effect

u_{000k} = random field center effect

e_{hijk} = random day within girl within school within field center effect

ii. Analyses for Aim 2b

Aim 2b examined whether MVPA on a given day is predictive of LPA on the same day or of LPA the following day. LPA was the dependent variable and MVPA was the independent variable. Three separate analyses were conducted with MVPA and LPA concurrently expressed in either absolute, relative, or intensity weighted terms

Data were analyzed using the general linear mixed model using PROC MIXED in SAS. The univariate association between MVPA and LPA as well as the multivariate association with covariates of interest were tested.

The multivariate mixed model for continuous variables takes the form of:

$$Y_{hijk} = \beta_{0ijk} + \beta_1 x_{1hijk} + \sum_{p=2}^{n} \beta_p x_{phijk} + u_{0ijk} + u_{00jk} + u_{000k} + e_{hijk}$$

Where:

Y_{hijk} = light physical activity on day *h* (or *h*+1 for the following day analysis) for girl *i* in school *j* and field center *k*

$\beta 0ijk$= mean light physical activity for girl *i* in school *j* and field center *k*

$\beta 1$= coefficient for the effect of MVPA on light physical activity

X_{1hijk} = MVPA on day *h* for girl *i* in school *j* and field center *k*

βp= coefficient for the effect of *p*th covariate on light physical activity

X_{phijk} = *p*th covariate from covariate vector consisting of race/ethnicity, BMI, percent body fat, SES, age, day of week, sample (8a or 8b), hours monitor was worn

u_{0jk} = random girl within school within field center effect

u_{00jk} = random school within field center effect

u_{000k} = random field center effect

e_{hijk} = random day within girl within school within field center effect

iii. Analyses for Aim 2c

Aim 2c examined whether MVPA on a given day was predictive of inactivity on the same day or of inactivity on the following day. Inactivity was the dependent variable and MVPA was the independent variable. Three separate analyses were conducted with MVPA and inactivity concurrently expressed in either absolute, relative, or intensity weighted terms (equivalent to absolute minutes for inactivity).

Data were analyzed using the general linear mixed model using PROC MIXED in SAS. The univariate association between MVPA and inactivity as well as the multivariate association with covariates of interest were tested.

The multivariate mixed model for continuous variables takes the form of:

$$Y_{hijk} = \beta_{0ijk} + \beta_1 x_{1hijk} + \sum_{p=2}^{n} \beta_p x_{phijk} + u_{0ijk} + u_{00jk} + u_{000k} + e_{hijk}$$

Where:

Y_{hijk} = daily inactivity on day h (or h+1 for following day analysis) for girl i in school j and field center k

β_{0ijk}= mean daily inactivity for girl i in school j and field center k

β_1= coefficient for the effect of MVPA on inactivity

X_{1hijk} = MVPA on day h for girl i in school j and field center k

β_p= coefficient for the effect of pth covariate on daily inactivity

X_{phijk} = pth covariate from covariate vector consisting of race/ethnicity, BMI, percent body fat, SES, age, day of week, sample (2005 or 2006), hours monitor was worn

u_{0jk} = random girl within school within field center effect

u_{00jk} = random school within field center effect

u_{000k} = random field center effect

e_{hijk} = random day within girl within school within field center effect

iv. Analyses for Aim 2d

Aim 2d examined whether MVPA on a given day ($MVPA_{Day1}$) was predictive of MVPA on the following day ($MVPA_{Day21}$). $MVPA_{Day2}$was the dependent variable and $MVPA_{Day1}$ was the independent variable. Three separate analyses were conducted with $MVPA_{Day1}$ and $MVPA_{Day2}$ concurrently expressed in either absolute, relative, or intensity weighted.

Data were analyzed using the general linear mixed model using PROC MIXED in SAS. The univariate association between $MVPA_{Day1}$ and $MVPA_{Day2}$ as well as the multivariate association with covariates of interest were tested.

The multivariate mixed model for continuous variables takes the form of:

$$Y_{hijk} = \beta_{0ijk} + \beta_1 x_{1hijk} + \sum_{p=2}^{n} \beta_p x_{phijk} + u_{0ijk} + u_{00jk} + u_{000k} + e_{hijk}$$

Where:

Y_{hijk} = MVPA on day h+1for girl i in school j and field center k

β0ijk= mean MVPA for girl i in school j and field center k

β1= coefficient for the effect of $MVPA_{Day1}$ on $MVPA_{Day2}$

X_{1hijk} = MVPA on day h for girl i in school j and field center k

βp= coefficient for the effect of pth covariate on $MVPA_{Day2}$

X_{phijk} = *p*th covariate from covariate vector consisting of race/ethnicity, BMI, percent body fat, SES, age, day of week, sample (8a or 8b), hours monitor was worn

u_{0jk} = random girl within school within field center effect

u_{00jk} = random school within field center effect

u_{000k} = random field center effect

e_{hijk} = random day within girl within school within field center effect

D. Strengths and limitations

1. Strengths

Previous observational studies that have assessed the relationship between inactivity and physical activity have quantified physical activity via self-report. We were able to obtain a more accurate measure of physical activity through use of accelerometry. These studies have also assessed inactivity through self-report of television viewing, which leaves many sedentary activities unmeasured. We were to obtain a more accurate measure of total time spent inactive using accelerometry.

While the use of prediction equations to establish physical activity intensity cutpoints for accelerometry has been met with some criticism, TAAG investigators developed population specific cutpoints for this purpose which should increase the accuracy of the measures. This study was unique in that the TAAG data set allows for the assessment of both cross-sectional and longitudinal relationships between physical activity intensities and total physical activity.

The primary strength of Aim 1, related to tracking of physical activity, is the use of an objective measure of inactivity and physical activity. Previous studies of tracking of inactivity and physical activity have largely used self-report measures.

Other strengths of this study include the large sample size and the ethnically and racially diverse sample of girls. These analyses were conducted in middle school girls, a population in need of a better understanding of factors associated with physical activity, which adds to the value of this study.

2. Limitations

Questions related to the regulation of physical activity would best be answered using an experimental design where physical activity and/or energy expenditure was measured on days where activity levels were manipulated to be above or below normal levels. However, observational studies may be able to advance the understanding of the relationship between physical activity intensity patterns and total physical activity in that patterns of physical activity may be indicative of a compensatory phenomenon. An argument for the existence of a compensatory phenomenon could be made if vigorous physical activity is inversely related to inactivity or to non-vigorous activity. Also, if inactivity is not associated with total physical activity it may be argued that regardless of how much time is spent in inactivity an individual may "make up for down time" by increasing vigorous activity. Additionally, the samples of girls in TAAG may not be representative of the entire middle school girl population in the United States.

E. IRB/ Human Subjects

Approval for this project was obtained through the Institutional Review Board of the University of North Carolina School of Public Health. All analyses were secondary data analysis. No additional contact was made with study participants. The TAAG investigators at each Field Center obtained IRB approval from their respective institutions for data collection.

V. Tracking of physical activity and inactivity in middle school girls: The Trial of Activity for Adolescent Girls

A. ABSTRACT

Purpose: The purpose of this study was to describe and compare the levels of tracking of physical activity and inactivity as assessed by self-report and accelerometry in middle school girls over a 2-year period. **Methods:** Participants (n=951) were from the Trial of Activity for Adolescent Girls (TAAG). At both 6^{th} and 8^{th} grades, inactivity and physical activity were measured using accelerometry (MTI Actigraph) and by self-report using the 3-day physical activity recall (3DPAR). **Results:** Weighted kappa statistics ranged from 0.14-0.17 across inactivity, moderate-to-vigorous physical activity (MVPA), and vigorous physical activity (VPA) for self-report, from 0.13-0.20 for 3-day accelerometry, and from 0.22-0.29 for 6-day accelerometry. Intraclass correlations ranged from 0.17-0.22 for self-report, 0.06-0.23 for 3-day accelerometry, and 0.16-0.33 for 6-day accelerometry. In general, the estimates from 6-day accelerometry tended to be higher than those from self report, while few differences were observed between 3-day accelerometry and self-report. Odds ratios for being in the highest quintile at 8^{th} grade for those in the highest quintile at 6^{th} grade, compared to those in any other quintile at 6^{th} grade were 3.26 (95% confidence interval=2.28, 4.67), 3.64 (2.55, 5.20), and 3.45 (2.42, 4.93) for 6-day accelerometry measured inactivity, MVPA, and VPA. Corresponding OR's from self-report were 2.44 (1.66, 3.58) for inactivity, 2.63 (1.83, 3.79) for MVPA,

and 2.23 (1.54, 3.23) for VPA. **Conclusion**: Tracking of inactivity and physical activity in middle school girls was fair-to-moderate. Our results suggest that physical activity and inactivity habits are dynamic for most girls during early adolescence. Population-based efforts should be made in this age group to promote physical activity and offer alternatives to inactivity for all girls.

B. INTRODUCTION

A number of studies have examined the stability, or tracking, of physical activity levels over time in children and youth. Tracking refers to the stability of relative rank or position within a group over time and is related to the ability to predict a measurement later in life knowing the value of the same variable earlier in life (18). Tracking of physical activity in children and youth is low-to-moderate at best; most tracking studies of children and youth have reported correlations of 0.30-0.60 depending on measurement method, age at baseline, and number of years between measurement (17, 19-21, 23-25, 60). These findings indicate that there is considerable within-person variability in physical activity levels during childhood and adolescence and that the ability to predict an individual's current or future physical activity levels based on past physical activity levels is modest.

Several studies have assessed tracking in childhood (17, 21, 25) and late adolescence (18, 23, 24), however few have focused on early adolescence (11-14 years of age) (20). Given the dramatic physiologic and psychosocial changes associated with puberty that occur during this time, it is feasible that tracking during early adolescence may be different than during other points in the lifespan. This may be particularly true in girls who begin sexual maturation earlier and move through the stages of maturation at a greater rate than boys during this time (61). At least one study has found that early maturing girls have lower activity levels than later maturing girls of the same age (62). Studies focusing on physical activity habits during this dynamic time of a girl's life may help identify adverse health behaviors that can be successfully targeted for intervention.

Self-reported physical activity is not usually precise, so it is plausible that the modest tracking of physical activity observed in studies that use self-reported measures was at least partly due to error inherent in the method. Objective measures of physical activity, such as accelerometry, may provide more accurate measures of physical activity habits than those obtained by self-report (63). To date, only a few studies have used an objective measure of physical activity to assess tracking of physical activity in youth (17, 21, 25, 26), none of which have focused on the early pubescent years (20). Even fewer studies have assessed the tracking of inactivity using either objective or subjective methods (20, 25, 26) during childhood and adolescence. Additional studies utilizing objective measurements, such as accelerometry, are needed to improve our understanding of the development and stability of physical activity habits in adolescents, which may translate into the development of more successful interventions. Additionally, no study has compared tracking measures as assessed by accelerometry and self-report methods. A comparison of this kind would provide information on the ability of self-report to measure this phenomenon.

The purpose of this study was to investigate the tracking of physical activity and inactivity as assessed by 3-days of self-report and 3- and 6-days of accelerometry in a racially diverse group of middle school girls. We also compared tracking measures between self-report and accelerometry.

C. 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 (7). TAAG has six field centers (at the Universities of Arizona, Maryland, Minnesota, 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 work. 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 girls, one drawn from 6^{th} graders at the beginning of the study in the spring of 2003, and a second drawn from 8^{th} graders in the spring of 2005 following the implementation of the 2-year intervention. Additionally, we recruited all 8^{th} grade girls who had been measured in 6^{th} grade in 2003 and who attended a TAAG school in the spring of 2005 regardless of whether they were identified as part of the 8th grade cross-sectional random sample. A total of 951 girls who were measured at both 6th grade and at 8th grade were included in the current analyses.

Measurements

Objectively measured physical activity and inactivity were assessed using the MTI Actigraph accelerometer model 7164 (Manufacturing Technologies Inc., Fort Walton Beach, Florida). Six complete days of Actigraph data were collected. Girls were instructed to wear the accelerometer on a belt around their waist over their right hip 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. (48). Missing actigraph data were imputed using the Expectation Maximization (EM) algorithm (49). Previous work in the TAAG cohort determined that MET thresholds ranges of 0- 2.09, 2.1- 4.59, 4.6- 6.49, and ≥ 6.5 METs best discriminated between activities classified as inactive, light, moderate and vigorous activity, respectively (48). These MET ranges corresponded to accelerometer count ranges of 0-50, 51-1499, 1500-2600, and > 2600 counts/30-seconds for inactivity, light, moderate, and vigorous activity, respectively (48).

Self-report of physical activity and inactivity was obtained using the 3DPAR (50). The 3DPAR is a modification of the Previous Day Physical Activity Recall, which has been validated in youth (64). Pate et al. (50) reported that 30-minute blocks of moderate-to-vigorous physical activity (MVPA) and vigorous physical activity (VPA) from the 3DPAR were significantly correlated with both 3 day (r=0.27-0.41) and 7 day (r=0.35-0.45) of Actigraph measurements. Girls recalled their past physical activity behavior for each of the three previous days. Each day was segmented into 36, 30-minute time blocks from 6 a.m. until midnight. A list of commonly performed activities was provided. Girls recorded the one activity that they performed for the longest period of time during each 30-minute time block. There was no lower limit set on the period of time that the activity identified was performed.

For non-sedentary activities, participants rated the intensity of the activity as light, moderate, hard, or very hard. Illustrations of individuals performing an activity at each of the four intensities were provided to help participants select the proper intensity. All activities classified as "inactivity" were assumed to only be performed at a single intensity. MET values were assigned to each block using standard published values (52). MET values used as cut points for classifying the activity in blocks as inactive, light, moderate or vigorous were the same shown above for accelerometry.

From the 3DPAR, the numbers of blocks classified in each intensity category each day were totaled, and daily averages were calculated for each girl. The 3-day average was used in the analyses of self-reported activity. For objectively measured activity, minutes spent in each intensity category were summed over the course of a day. Two averages were obtained: one using all 6 days measured and another limited to the same 3 days that were assessed using the 3DPAR in order to assess any differences between measurement methods that were a result of differing number of days and type of days (weekend versus weekdays).

At the completion of the 6-day Actigraph monitoring period, participants completed the 3DPAR. This protocol resulted in having data from both self-report and Actigraph on three corresponding days. The 3DPAR was most frequently completed on a Wednesday (33%) or a Tuesday (28%) and was never completed on a Saturday or Sunday. Therefore, weekend days were over-represented in the 3-day sample with 47% weekdays and 53% weekend days assessed, as opposed to the 71% weekdays and 29% weekend days that would be expected had the sampling of days been uniform. The 6-day accelerometry data were less skewed with 67% of the data from weekdays and 33% of the data from weekend days. Previous work from TAAG has shown that physical activity levels differ by day of week (65).

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 (53).

Race/ethnicity was indicated via self-report on a six-item checklist which included (1) Caucasian (White, non-Hispanic), (2) African-American, (3) Hispanic, (4) Asian/Pacific Islander, (5) American Indian, and (6) Other. A proxy measure of socio-economic status (SES) was assessed at the school level by obtaining the proportion of students who received free or reduced cost lunch during the 2002-2003 school year.

Exclusions

In the 6th grade sample of girls, consent was obtained from 1721 girls. Of these girls, 118 had incomplete accelerometry data, 54 had fewer than three days of physical activity recall, 19 had incomplete body composition measures, seven were missing age, and one was missing race/ethnicity. Of the 1522 girls with complete measures in the 6th grade, 1243 were also assessed in the 8th grade sample. Among these girls 290 had incomplete or missing accelerometry data and two had fewer than three days of physical activity recall. Thus, 951 girls provided data for the current analyses. Body composition and MVPA did not differ between those girls measured at both 6th and 8th grade compared to those measured only at 6th grade.

Statistical analysis

Statistical analyses were conducted using SAS version 8.02 (SAS Institute, Cary, NC). There were only trivial differences in the tracking measures in the girls assigned to intervention and control schools, and therefore the data were combined for all analyses. Weighted kappa statistics (58) were calculated to assess the agreement in inactivity and different intensities of activity between baseline and follow-up (tracking). In order to calculate the kappa statistics, data were categorized into quintiles. The kappa statistics were interpreted according to the recommendations of Munoz and Bangdiwala (66), whereby a Kappa-value of <0.00 equates to poor strength of agreement, 0.00–0.20 is fair agreement, 0.21–0.45 is moderate agreement, 0.46–0.75 is substantial agreement, and 0.76–1.0 is almost perfect agreement. Differences in the kappa statistics were assessed using the method described by McKenzie (59) to compare kappas drawn from the same sample.

Intraclass correlations (ICC) between 6th grade and 8th grade were calculated using PROC MIXED and methods described by Fleiss and Shrout (56). Differences between the ICCs were assessed using the method described by Donner and Zou (67) to compare correlations drawn from dependent samples. The odds of being in a specific quintile of MVPA, VPA, and inactivity at 8th grade given assignment in the same quintile at 6th grade, relative to those in any other quintile at 6th grade, were assessed using a logistic mixed model. For the ICC and logistic models field center and school within field center were included as random effects in all models. Covariates tested included race/ethnicity, BMI, percent body fat, SES, age, and intervention assignment (treatment or control). Inclusion of these variables in the models did not improve the fit (p>0.05), and none of the estimates changed by more than 8% when the variables were included. Therefore, these potential covariates were not included in the analyses shown here.

D. RESULTS

Table 5.1. Descriptive characteristics [mean (SD) or percent] of girls measured at 6th and 8th grade in the TAAG study (n=951).

	6th grade mean (SD) or %	8th grade mean (SD) or %
Age (yrs)	11.9 (0.4)	13.9 (0.4)
Weight (kg)	48.4 (13.8)	58.1 (15.0)
BMI (kg/m^2)	20.7 (4.7)	22.5 (5.2)
% Body Fat	27.8 (9.2)	31.2 (8.3)
Accelerometer (minutes/day)		
Inactivity	460.6 (67.3)	513.2 (62.5)
MVPA	23.4 (11.6)	21.8 (10.7)
VPA	5.6 (4.7)	5.1 (4.0)
Self-report (30-minute blocks/day)		
Inactivity	28.7 (3.4)	28.9 (3.1)
MVPA	1.9 (2.1)	1.5 (1.9)
VPA	1.3 (1.6)	1.0 (1.4)
Race/ethnicity (%)		
White	51.8	-
African-American	19.2	-
Hispanic	19.1	-
Asian/Pacific Islander	4.5	-
Other	5.3	-

Table 5.1 shows descriptive characteristics of the girls measured in the 6th and 8th grades. The sample was racially diverse (48.2% non-white). The mean time between measurements was 2 years (SD=0.14). On average, body weight, BMI, and percent body fat were higher in 8th than in 6th grade. There was an increase in accelerometer-measured inactivity, while self-reported inactivity was relatively stable. MVPA and VPA tended to decline from 6th to 8th grade for both accelerometer-measured and self-reported activity.

Table 5.2 presents the sample sizes and ranges of values across quintiles of inactivity, MVPA, and VPA for 6-day accelerometry and self-report. For objectively-measured physical activity the sample sizes within the quintiles were almost identical. The ranges of the measured minutes were much larger in the extreme quintiles (quintiles 1 and 5) than in quintiles 2, 3, or 4. For example, in 6th grade the spans were 124 and 178 minutes respectively in the first and fifth quintiles, whereas the span was only 32 minutes in the middle quintile. The same trends were found in the 3-day means from accelerometry (data not shown).

The distribution of self-reported blocks of inactivity also showed larger spans in the extremes and relatively even numbers of participants within the 5 quintiles. However, for MVPA and VPA ties resulted in an uneven number of girls within quintiles. This was most evident for VPA in 8th grade as 421 girls (44% of the sample) reported no blocks. For this reason, self-reported VPA was analyzed in four, rather than five categories.

Table 5.2. Range (n) of measured values within each quintile of inactivity, MVPA and VPA for 6-day accelerometry and self-report.

	Quintile 1	2	3	4	5
Accelerometry (minutes/day)					
Inactivity					
6th Grade	282.5-406.6 (191)	406.7-441.2 (190)	441.3-473.4 (190)	473.6-517.7 (190)	518.6-696.8 (190)
8th Grade	309.9-460.0 (191)	461.0-493.7 (190)	493.8-525.0 (190)	525.2-562.9 (190)	563.0-752.1 (190)
MVPA					
6th Grade	2.6-13.9 (191)	13.9-18.8 (190)	18.8-24.2 (190)	24.3-31.6 (190)	31.6-87.8 (190)
8th Grade	2.0-13.2 (191)	13.2-17.4 (190)	17.5-22.2 (190)	22.2-29.4 (190)	29.4-76.3 (190)
VPA					
6th Grade	0.2-2.4 (191)	2.4-3.6 (190)	3.6-5.1 (190)	5.2-8.0 (190)	8.0-49.6 (190)
8th Grade	0.3-2.3 (191)	2.3-3.4 (190)	3.4-4.6 (190)	4.6-7.3 (190)	7.3-31.0 (190)
Self-report (blocks/day)					
Inactivity					
6th Grade	12.7-26.0 (201)	26.3-28.3 (207)	28.7-30.0 (192)	30.3-31.3 (161)	31.7-36.0 (190)
8th Grade	16.3-26.3 (198)	26.7-28.3 (183)	28.7-30.0 (210)	30.3-31.7 (205)	32.0-36.0 (155)
MVPA					
6th Grade	0.0-0.0 (201)	0.3-0.7 (187)	1.0-1.7 (204)	2.0-3.0 (174)	3.3-15.0 (185)
8th Grade	0.0-0.0 (317)	0.3-0.7 (152)	1.0-1.3 (126)	1.7-2.7 (176)	3.0-15.3 (180)
VPA					
6th Grade	0.0-0.0 (284)	0.3-0.7 (233)	1.0-1.0 (69)	1.3-2.0 (184)	2.3-12.3 (181)
8th Grade*	0.0-0.0* (421)		0.3-0.7 (183)	1.0-1.7 (168)	2.0-12.3 (179)

*Quintiles 1 and 2 combined due to 44% of girls reporting zero blocks of VPA at 8th grade

Weighted kappa statistics and intraclass correlations for self-report and 3- and 6-day accelerometry are presented in Table 5.3. For self-report and 3-day accelerometry measures the kappa statistics suggested fair agreement between 6th and 8th grade, while the kappa statistic from 6 days of accelerometry indicated moderate agreement. Kappas ranged from 0.14-0.17 across inactivity, MVPA, and VPA for both self-report and 3-day accelerometry, and from 0.22-0.29 for 6-day accelerometry. Significant differences ($p<0.05$) were observed between kappa statistics produced from self-report and 6-day accelerometry, with the kappas from 6-day accelerometry being higher for inactivity and MVPA. No differences were observed between kappas from self-report and 3-day accelerometry.

For self-report as well as 3- and 6-day accelerometry the highest ICCs were for MVPA (ICC = 0.22, 0.23, and 0.33, respectively), while the lowest ICCs were for inactivity (ICC = 0.17, 0.06, 0.16 respectively). The ICC of inactivity for 3-day accelerometry was significantly lower ($p<0.05$) then that from self-report. ICCs for MVPA and VPA were significantly higher ($p<0.05$) from 6-day accelerometry compared to self-report for MVPA and VPA.

Table 5.3. Assessment of tracking of physical activity and inactivity over 2-years comparing the same measure at 6th and 8th grade using weighted kappa statistics and intraclass-correlations (ICC) (95% CI) for self-report and accelerometry.

	Self-Report		*Accelerometery*			
	Weighted Kappa 3-day	ICC 3-day	Weighted Kappa 3-day	ICC 3-day	Weighted Kappa 6-day	ICC 6-day
Inactivity	0.14 (0.10, 0.18)	0.17 (0.17, 0.17)	0.13 (0.08, 0.17)	0.06* (0.06, 0.07)	0.26* (0.21, 0.30)	0.16 (0.15, 0.16)
MVPA	0.17 (0.13, 0.22)	0.22 (0.21, 0.22)	0.20 (0.16, 0.24)	0.23 (0.20, 0.25)	0.29* (0.24, 0.33)	0.33* (0.32, 0.33)
VPA	0.17 (0.12, 0.22)	0.17 (0.16, 0.17)	0.17 (0.13, 0.22)	0.19 (0.17, 0.20)	0.22 (0.18, 0.27)	0.25* (0.24, 0.25)

* Different from corresponding self-report statistic ($p < 0.05$).

Table 5.4. Odds of being in a given quintile* of inactivity, MVPA, and VPA in 8th grade for those in the same quintile at 6th grade, relative to those in any other quintile at 6th grade.

	Odds ratio (95% CI) for 8th grade quintile				
	1	2	3	4	5
Accelerometry					
Inactivity	2.86 (2.01, 4.08)	1.89 (1.32, 2.72)	1.32 (0.90, 1.93)	1.58 (1.09, 2.30)	3.26 (2.28, 4.67)
MVPA	3.38 (2.37, 4.83)	1.47 (1.01, 2.14)	1.37 (0.94, 1.99)	1.38 (0.94, 2.01)	3.64 (2.55, 5.20)
VPA	3.59 (2.53, 5.10)	1.22 (0.83, 1.79)	1.39 (0.96, 2.03)	1.22 (0.83, 1.79)	3.45 (2.42, 4.93)
Self-report					
Inactivity	1.84 (1.29, 2.63)	1.01 (0.68, 1.49)	1.12 (0.78, 1.63)	1.56 (1.07, 2.29)	2.44 (1.66, 3.58)
MVPA	1.80 (1.30, 2.47)	1.39 (0.92, 2.09)	1.36 (0.88, 2.09)	1.27 (0.84, 1.89)	2.63 (1.83, 3.79)
VPA	1.74** (1.31, 2.31)		0.90 (0.47, 1.72)	1.33 (0.89, 1.99)	2.23 (1.54, 3.23)

*Logistic mixed models: logit [8th grade quintile] = 6th grade quintile + (Site + School within Site included as random effects).
**Quintiles 1 and 2 combined due to 44% of girls reporting zero blocks of VPA at 8th grade

To calculate the odds ratios shown in Table 5.4, dichotomous variables were created to indicate whether or not a girl's inactivity or activity was in a given category in 6th and 8th grades. These analyses showed that for accelerometry-measured activity and inactivity, the odds of being in the same quintile in both 6th and 8th grade were greatest for those in the extreme quintiles, while the odds of remaining in the middle three quintiles were smaller and generally not significantly different. For example, the odds of being in the highest quintile of inactivity (the most inactive) at 8th grade was greatest for those in quintile 5 at 6th grade (OR [95% CI]=3.26 [2.28, 4.67]) compared to those in any other quintile at 6th grade (quintiles 1-4), while the odds of being in the third quintile of inactivity at 8th grade was no different for those in the third quintile at 6th grade (OR [95% CI]=1.32 [0.90, 1.93]) compared to those in any other quintile at 6th grade (quintiles 1, 2, 4, 5) .

The odds ratio for being in a given quintile of self-reported inactivity, MVPA, and VPA in 8th grade given assignment in the same quintile at 6th grade are also presented in table 5.4. In general these odds ratios were smaller than those from accelerometry, but displayed a similar trend. The odds of remaining in the same quintile in both 6th and 8th grade were greatest for those in the extreme quintiles, while the odds of remaining in any of the middle three quintiles was not significantly different from those in any other quintile at 6th grade.

E. DISCUSSION

This study showed that over a 2-year period tracking of physical activity and inactivity in middle school girls was fair to moderate depending on the assessment method and the days measured. Six days of accelerometry tended to provide higher tracking measures than three days. When the 3 days measured were matched, tracking assessments were similar whether measured by self-report or accelerometry.

To our knowledge this is the first study to assess the tracking of physical activity and inactivity in middle school girls using accelerometry. Accelerometry generally provides a more accurate and reliable measure of physical activity than self-report (53, 68). Earlier results from the TAAG study suggested that the reliability and validity of the 3DPAR decreased with each day of recall compared to accelerometry (48). It might be expected that the greater precision and repeatability associated with accelerometry would lead to higher tracking measures compared to self-report. Nevertheless, our results suggested little difference between tracking measures of MVPA or VPA compared to those from self-report when the measurement days used were matched. Only when physical activity was measured over 6-days did accelerometry produce higher tracking measures than 3DPAR.

The discrepancies in the comparison of 3DPAR to accelerometry from 3-days versus 6-days may be due to the percentage of days measured that were weekend days. It is known that there is greater variability (lower ICCs) in physical activity measurement on weekends versus on weekdays (48, 69, 70) when assessed by accelerometry. Thus the over-representation of weekend days in our 3-day matched analysis may have resulted in lower tracking. It was interesting that the measured tracking was so similar between self-report and accelerometry in the 3-day matched analysis. This does not mean that self-report and accelerometry quantify physical activity and inactivity levels equally well, but that that the two assessment methods may have similar abilities to evaluate changes in physical activity and inactivity over time. Self-report may provide a good measure of tracking that requires less monetary resources and subject burden compared to accelerometry. Additional work is needed comparing tracking measures of physical activity and inactivity from self-report to accelerometry with varying number of days.

We know of only three studies that have used accelerometry to assess tracking of physical activity in youth. In the Iowa Bone Development Study (25), accelerometers were used to assess tracking of physical activity over a 3-year period in a group of elementary-school aged boys and girls. Spearman rank-order correlation coefficients between baseline and follow-up MPA and VPA were modest (r = 0.32 -0.40). Wilkin et al.(17) assessed tracking of physical activity using accelerometry in elementary school aged children over a one-year period. Correlations for daily activity between years were moderate (r=0.49 total, r=0.36 girls, r=0.55 boys, all P<0.001). Kelly et al. (26)

observed Spearman rank correlations of 0.35-0.37 for total PA, inactivity, and MVPA in a small group of young children (mean age at baseline 3.8 years) over a 2-year period. Raw kappa statistics were 0.17, 0.013, and 0.21 for total PA, sedentary behavior, and MVPA, respectively. All of these studies used the same accelerometer model we used, the data were reduced using alternate methods, and the length of time the monitors were worn varied; however, the conclusions from these studies are similar to ours in that fair-to-moderate tracking of accelerometer measured physical activity and inactivity was found.

Tracking in girls similar in age to those studied here has been examined using self-report measures. Janz and colleagues (20) assessed tracking of vigorous activity and television viewing/video game playing over a five year period in a small group of early adolescent girls (n=62, mean age at baseline=10.3 years). Vigorous activity was assessed using the 3-day Sweat Recall and television viewing/video game playing using an interviewer administered previous day recall. They found strong tracking of vigorous activity with Spearman correlations between year 5 and each of the 4 preceding years ranging from 0.43-0.65. Low tracking was found in TV/video game recall except between years 5 and 4 (Spearman correlation=0.59); Spearman correlations between year 5 and years 1-3 ranged from 0.16-0.26. Thus, similar to our study, Janz et al. found tracking in self-reported activity and inactivity in adolescent girls. Discrepancies in the estimated level of tracking may have been influenced by differences in the measurement intervals and the recall methods used.

Intuitively tracking should increase as the time interval between measures decreases. The 2-year interval examined here is relatively brief. However, early adolescence is a stage in life of particularly great biological, as well as psychosocial changes, which may result in substantial changes in physical activity and inactivity levels. Indeed, Baker et al. (62) have demonstrated that 11-year-old girls who experienced puberty early relative to their peers had lower objectively measured physical activity at age 13 than later maturing girls, even after controlling for differences in physical activity and body composition at age 11. Although we do not have a measure of pubertal status our mean age at baseline was 11.9 years and at follow-up was 13.9 years. Nationally representative data from NHANES III indicated that at age 11.7 approximately 25% of girls had experienced first menstruation, while 2 years later 90% of girls had achieved menarche (71). Differences in the timing and tempo of sexual maturation throughout our 2-year measurement period and changes in activity associated with maturation may have reduced tracking. Additional research is needed focusing on the physiologic, as well as psychosocial and environmental determinants of tracking of physical activity habits in this age group.

The odds of remaining in the same quintile of accelerometry assessed inactivity, MVPA, and VPA over 2 years were higher than being in a different quintile, and this effect was larger and statistically significant at the extremes of the distribution. This effect in the extreme quintiles may be due to the large range of the measured variables in the extreme quintiles compared to the range in the middle three quintiles. On average, a much greater change in minutes or blocks would be needed in order to move from either the lowest or highest quintile at 6th grade into another quintile at 8th grade, while moving from one of the middle quintiles would require a smaller change. Although the size of the odds ratios from self-report tended to be smaller than those from 6-day accelerometry, the trends were similar. The highest odds were seen for those in the extreme quintiles at 6^{th} grade.

Our study had several limitations. The 3DPAR has been validated for the measurement of total physical activity, MVPA, and VPA, but not for inactivity. It should be noted that our use of a 3-day accelerometry measure is not consistent with the current recommended guidelines for accelerometry use in adolescents of 4-9 days in order to obtain a reliable measure of physical activity (69). Another limitation of this study is that comparisons of the 3- and 6-day accelerometry measures were complicated by the mixture of weekdays versus weekend days assessed.

The primary strength of this study was the use of both accelerometry and self-report to quantify the tracking of physical activity and inactivity. Additionally, we used population specific intensity cut points to determine time spent in inactivity, MVPA, and VPA. We used three different statistical methods to quantify tracking, and this allowed us to better understand complexities of the issue. Kappa statistics and ICCs provided global measures of agreement and described agreement over the entire distribution, while the odds ratios allowed us to look within specific portions of the distribution to identify where agreement occurred. The ICC analyzed the activity and inactivity data as continuous variables, whereas the kappas and odds ratios examined data in categories. The ICC and odds ratio analyses tested for influences of demographic characteristics of the participants on tracking. Finally, this study included a larger, more ethnically diverse sample than has been previously reported in the literature for accelerometry measured tracking of physical activity and inactivity.

Our results suggest that physical activity and inactivity habits are dynamic for most girls during early adolescence. Efforts should be made in this age group to promote physical activity and offer alternatives to inactivity to all girls, not just those presently inactive, in order to maintain or increase activity levels in those already active as well as increase activity in those currently inactive. Intervention may be necessary to achieve recommended levels of activity in the most inactive and least active girls, who have a propensity to maintain these health behaviors during early adolescence.

VI. Associations between physical activity and inactivity in middle school girls: The Trial of Activity for Adolescent Girls

A. ABSTRACT

Purpose: The "activitystat" hypothesis suggests that increases in an individual's moderate-to-vigorous physical activity (MVPA) are accompanied by a compensatory reduction in light physical activity (LPA) and an increase in inactivity in order to maintain a consistent total physical activity level. The purpose of this study was to determine if such compensatory changes exist and result in the maintenance of total physical activity levels among middle school girls. **Methods:** Participants were 6,916, 8^{th} grade girls from the Trial of Activity for Adolescent Girls (TAAG). Inactivity and physical activity were measured over 6- consecutive days using accelerometry (MTI Actigraph). A within-girl, repeated measures design was utilized to assess the associations between physical activity and inactivity using general linear mixed models. **Results:** Within a given day**,** a 1 MET-minute increase in inactivity of was associated with a decrease of -3.18 MET-minutes (95% confidence interval: -3.19, -3.17) of total physical activity (activity > 2 METS) on the same day. Daily inactivity was negatively associated with total physical activity on the following day. A 1-minute increase in MVPA was associated with a decline in inactivity of 1.85 minutes 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 were not consistent with the

“activitystat” hypothesis. These findings indicate that increases in MVPA result in a decline in inactivity and decreases in inactivity result in increases in total physical activity.

B. INTRODUCTION

It has been hypothesized (16) 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. It is suggested (16) that physical activity, just like internal body temperature, pH, and blood pressure, is kept within narrow tolerance limits in order to maintain energy balance. The “activitystat” would keep total physical activity constant across by increasing/decreasing the frequency, intensity, and/or duration of time spent in one of the components of total physical activity to compensate for increases/decreases in the other component of total physical activity.

As demonstrated in figure 3.1, as MVPA increases across the three days, 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 3.1, 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” compensates for the periods of inactivity by increasing the intensity of activity during the rest of the day in order to maintain the total physical activity set-point. Both observational (17, 35, 36) and experimental studies (28, 38) have examined the compensation phenomenon in children and youth with inconsistent findings. The existence of compensation in physical activity would limit, if not negate, the impact increased opportunities for physical activity may have. Physical activity declines considerably during adolescence and thus youth in this age group are prime candidates for interventions targeting these behaviors. Further research is needed to determine if compensation occurs during adolescence so that physical activity interventions may be developed accordingly.

The "activitystat" hypothesis would appear to be in opposition to the displacement hypothesis. The displacement hypothesis suggests that television watching and other sedentary behaviors displace physical activity (72). Increased time spent inactive has been suggested to be a primary factor contributing to the current increases in obesity seen in adolescents (13, 73, 74). Inactivity requires little to no extra energy expenditure above that of resting levels, and may reduce the time spent being physically active.

If time spent inactive displaces physical activity then an inverse relationship between inactivity and moderate-to-vigorous physical activity (MVPA) or total physical activity would be expected. However, there is little data that supports the existence of such relations (75). These findings suggest that a better understanding of the associations between inactivity and total physical activity and its components (time spent in light and moderate-to-vigorous physical activity) is needed.

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 present analysis was to determine if relations exist between inactivity and total physical activity and its components that are suggestive of compensatory changes that would result in the maintenance of total physical activity levels or displacement of physical activity by inactivity. Specific questions addressed include: 1) does inactivity on a given day affect total physical activity on the same day or on the following day; 2) does MVPA on a given day affect inactivity on the same day or on the following day?; and 3) does MVPA on a given day affect LPA on the same day or on the following day?

C. 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 (7). 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 (7) included two cross-sectional samples of 8^{th} grade girls, one drawn in the spring of 2005, and the second drawn in the same schools in the spring of

2006. 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. (48). Missing Actigraph data were imputed using the Expectation Maximization (EM) algorithm (49). Previous work in the TAAG cohort determined that metabolic equivalent (MET) threshold ranges of 0- 2.09, 2.1- 4.59, 4.6- 6.49, and ≥ 6.5 METs best discriminated between activities classified as inactive, light, moderate, and vigorous activity, respectively (48). These MET ranges corresponded to accelerometer count ranges of 0-50, 51-1499, 1500-2600, and > 2600 counts/30-second interval for inactivity, light, moderate, and vigorous activity, respectively (48). 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 (52). MET-weighted minutes were calculated as the sum of the MET values for each 30-epoch within a given intensity range divided by 2 (to convert 30-second intervals to minutes).

Three approaches were used to quantify daily LPA and MVPA: 1) MET-weighted minutes; 2) absolute minutes; and 3) percentage of monitored time (number of hours monitor was worn and recorded valid data each day) spent in LPA or MVPA. Total physical activity (all activity above the inactive threshold) was derived using these same three approaches: 1) total MET-minutes of LPA and MVPA; 2) total minutes spent in LPA and MVPA; 3) percentage of monitored time spent in LPA and MVPA. Since inactivity has a MET value of 1, absolute minutes spent inactive and MET-minutes of inactivity have the same value, therefore we only quantified inactivity using 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 (53).

Percent body fat was estimated from anthropometric measures using an equation that was developed by TAAG investigators for use in middle school girls: percent fat = -23.39 + 2.27 (BMI) + 1.94 (triceps skinfold, mm) – 2.95 (race, 1 if African American, else 0) – 0.52(Age, yrs) – 0.06(BMI x triceps skinfold, mm). The equation was shown to have an R^2 of 0.88 for predicting percent body fat against the same measure obtained from DEXA (53).

Race/ethnicity was indicated via self-report on a six-item checklist which included (1) Caucasian (White, non-Hispanic), (2) African-American, (3) Hispanic, (4) Asian/Pacific Islander, (5) American Indian, and (6) Other. A proxy measure of socio-economic status (SES) was assessed at the school level by obtaining 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). Pearson correlations coefficients were calculated using 6-day means for the physical activity intensity and total physical activity variables. Correlations between variables were assessed for minutes, MET-minutes, and % of day.

A within-girl repeated measures design was utilized to assess the associations between total physical activity and physical activity intensity patterns using general linear mixed models. This design allows a separate intercept and slope to be estimated for each participant using data from each of the 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 each model tested the independent variable and all covariates were treated as fixed effects. Continuous variables of BMI, percent body fat, age, SES, and total hours of monitored time on a given day (centered at 14 hours) were examined as potential covariates along with categorical variables of race/ethnicity, day of the week, and cross-sectional sample (2005 or 2006) from which the girls were drawn. Due to the low percentage of American Indians (<1%), these participants were grouped in the "Other" category and thus race/ethnicity was a 5-level categorical variable. Day of the week was included as a 7-level categorical variable. Models where physical activity was expressed in MET-minutes or minutes included only race/ethnicity, day of week, cross-sectional sample, and monitored time for the analyses presented. Similar covariates were incorporated in the models where physical activity was expressed as a percentage of the monitored time, except monitored time was not included in these models. Models including the covariates described above along with BMI, percent body fat, age, and SES, either by themselves or in combination with each other, did not improve the fit of the models ($p>0.05$), and none of the estimates changed by more than 2% when these variables were included.

The model for study question 1 was designed to examine whether inactivity on a given day is predictive of total physical activity on the same day. Total physical activity was the dependent variable and inactivity was the independent variable. Study question 2 examined whether MVPA on a given day is predictive of inactivity on the same day. Inactivity was the dependent variable and MVPA was the independent variable. Study question 3 examined whether MVPA on a given day was predictive of LPA on the same day. LPA was the dependent variable and MVPA was the independent variable.

We also explored whether there was a one day time lag in any compensatory relationships between total physical activity and physical activity intensity patterns. To do this, we repeated the same analyses for the three questions described, however the independent variable was from a given day while the dependent variable was from the following day. For example, we examined whether inactivity on Monday was predictive of total physical activity on Tuesday. Additionally, we examined the relationship between MVPA on a given day and MVPA on the following day to explore whether a 24-hour compensatory relationship existed for MVPA.

D. RESULTS

Table 6.1. Descriptive characteristics of study participants (N=6,916).

	Mean or % (SD)
Age	14.0 (0.5)
BMI	22.8 (5.3)
BMI Status (%)	
Normal weight	65.5
Overweight	17.0
Obese	17.5
Race/ethnicity (%)	
White	46.3
Hispanic	21.6
African-American	19.8
Asian/Pacific Islander	5.2
Other	7.1
Inactivity	
Minutes	521.5 (63.4)
% of day	62.8 (6.2)
Light Physical Activity	
Minutes	298.0 (50.9)
MET-minutes	896.1 (170.2)
% of day	35.9 (5.6)
MVPA	
Minutes	21.9 (11.2)
MET-minutes	133.5 (74.3)
% of day	2.6 (1.3)
Total Physical Activity	
Minutes	918.0 (177.9)
MET-minutes	320.0 (55.3)
% of day	38.5 (6.2)
Monitored time (hours/day)	13.9 (1.0)

Abbreviations: BMI- body mass index, MVPA- moderate-to-vigorous physical activity

Table 6.1 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 values over the 6-days of measurement. On average, participants spent more than 60% of each day inactive. Participants averaged only 22 minutes of MVPA per day, accounting for less than 3% of monitored time per day.

Table 6.2 presents Pearson correlations between inactivity, LPA, MVPA, and total physical activity. Whether physical activity or inactivity was expressed as minutes, MET-minutes, or as a percentage of the day, the direction and magnitude of each of the associations were 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. All correlations were significantly greater than zero ($p < 0.001$).

Table 6.2. Correlation matrices for physical activity intensities and total physical activity expressed as minutes, MET-minutes, and percent of monitored time.

	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	-1.00	0.98	0.50

Abbreviations: LPA- light physical activity, MVPA- moderate-to-vigorous physical activity, Total PA- total physical activity
$p < 0.001$ for all correlations

Table 6.3 displays the results of the analyses comparing the relations of interest on the same day. Each coefficient estimates the change in the dependent variable on a given day within a girl associated with a one-unit increase in the independent variable within a girl on the same day. For example, the estimate for MVPA, expressed as minutes, predicting inactivity is -1.85. This means that for every 1 minute a girl increases her MVPA on a given day, there is a reduction of 1.85 minutes of inactivity on the same day. Or, for every 10 minutes a girl increases her MVPA on a given day, there is a reduction of 18.5 minutes of inactivity on the same day. The coefficients for each of the three models was statistically significant (p < 0.01), whether physical activity was expressed as minutes, MET-minutes, or % of day. Additionally, all of the coefficients were in the same direction regardless of how physical activity was expressed.

Table 6.3. Associations between selected physical activity variables for analyses comparing variables on the same day*.

	MET-minutes[1] β (95% CI)	Minutes[1] β (95% CI)	% of Monitored Time[2] β (95% CI)
		Inactivity	
Total PA	-3.18 (-3.19, -3.17)	-1	-1
		MVPA	
Inactivity	-0.25 (-0.25, -0.24)	-1.85 (-1.89, -1.82)	-1.85 (-1.89, -1.82)
		MVPA	
LPA	0.38 (0.36, 0.39)	0.85 (0.82, 0.89)	0.85 (0.82, 0.89)

Abbreviations: LPA- light physical activity, MVPA- moderate-to-vigorous physical activity, Total PA- total physical activity, 95%CI- 95% confidence interval.
* p < 0.01 for all associations
[1]Linear mixed model: Dependent Variable = Independent Variable + Monitored time + Day of week + Sample + Race + (Field center + School within field center + Girl within school within field center included as random effects).
[2]Linear mixed model: Dependent Variable = Independent Variable + Day of week + Sample + Race + (Field center + School within field center + Girl within school within field center included as random effects).

Table 6.4 displays the results of the analyses comparing the relationships of interest with the independent variable on a given day predicting the dependent variable on the following day. For these analyses the coefficient estimates the change in the dependent variable on a given day within a girl associated with a one-unit increase in the independent variable within a girl on the previous day. For example, the estimate for MVPA, expressed as MET-minutes, on a given day predicting inactivity on the following day is -0.05. That is, for every 1 MET-minute increase in MVPA on a given day, there is a decrease in inactivity of 0.05 minutes the following day. As with 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 are greatly reduced; however the associations are all in the same direction as the analogous models in the same day analyses.

Table 6.4. Associations between selected physical activity variables for analyses comparing variables on the following day*.

	MET-minutes[1] *β (95% CI)*	*Minutes*[1] *β (95% CI)*	*% of Monitored Time*[2] *β (95% CI)*
Model			
Total PA = Inactivity	-0.80 (-0.84, -0.76)	-0.28 (-0.29, -0.26)	-0.22 (-0.23, -0.21)
Inactivity = MVPA	-0.05 (-0.06, -0.04)	-0.37 (-0.43, -0.31)	-0.11 (-0.15, -0.07)
LPA = MVPA	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, MVPA- moderate-to-vigorous physical activity, Total PA- total physical activity, 95%CI- 95% confidence interval.
* $p < 0.01$ for all associations
[1]Linear mixed model: Dependent Variable = Independent Variable + Monitored time + Day of week + Sample + Race + (Field center + School within field center + Girl within school within field center included as random effects).
[2]Linear mixed model: Dependent Variable = Independent Variable + Day of week + Sample + Race + (Field center + School within field center + Girl within school within field center included as random effects).

E. DISCUSSION

This study examined the associations between total physical activity and physical activity intensity patterns in order to determine whether relationships indicative of compensatory changes in adolescent girls. Our results show significant relationships between total physical activity, light physical activity, and moderate-to-vigorous activity;

however the associations are not in the direction we would expect if compensation were to occur. These findings suggest that as girls increased their inactivity total physical activity decreased, as MVPA increased inactivity decreased, and as MVPA increased light physical activity increased. Additionally, as MVPA on a given day increased, MVPA on the following day also increased. Taken together these results lead us to conclude that compensation in physical activity does not occur within a given day nor does compensation occur on the following day as a result of physical activity or inactivity on the previous day, however inactivity may displace physical activity.

The results from the same day analyses indicate that total physical activity declined 3.18 MET-minutes for each additional minute of inactivity. A similar inverse relationship existed between MVPA and inactivity. As MVPA increased inactivity decreased. For every one MET-minute increase in MVPA, inactivity decreased by 0.25 minutes. A positive association was found between MVPA and LPA. All of these results suggest that, within the same day, compensatory changes that would result in maintenance of total physical activity at a set level do not occur.

On any given day there are a finite number of minutes monitored, which is the sum of the minutes of inactivity and minutes of total physical activity (LPA and MVPA). As inactivity, expressed in minutes or percent of time monitored, increases or decreases there is an equal, but opposite effect in total physical activity. That is, as inactivity increases total physical activity should decrease a proportional amount, and vice versa. The coefficients for the relationship between total physical activity and inactivity, expressed in minutes or as % of time monitored, demonstrate this relationship with both coefficients being equal to -1. The use of the MET-weighted model demonstrates that the inverse relationship between inactivity and total physical activity is not just due to an exchange of minutes, but that an increase in inactivity is associated with a decrease in the intensity of activity performed on a given day. For the following day analyses, this is less of an issue since the inverse proportional relationship between inactivity and total physical activity only exists within the same day.

Results for the following day analyses suggest that compensatory changes do not occur on a given day 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 and may not be of physiologic significance. For instance, as MVPA on a given day increased LPA on the following day increased 0.03 MET-minutes or 0.06 minutes. Nevertheless, even a null relationship between these variables is suggestive of a lack of compensation, as we would expect LPA to decrease as MVPA increases in order to maintain total physical activity at a set-point.

While our results may not support the “activitystat” hypothesis, our findings suggest that displacement of physical activity could be occurring. Previous studies that have examined the associations between inactivity and physical activity have largely quantified inactivity via self-report of a selected number of sedentary behaviors (75); 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 equivocal associations between inactivity and physical activity in these studies. Other sedentary behaviors of children, such as talking on the phone or listen to music, should also be considered. Our use of accelerometry provides a broad measure of all time spent inactive, which may account for the larger inverse association between inactivity and MVPA and inactivity and total physical activity observed in this study.

Although there are few studies that have directly examined compensatory changes in physical activity, several observational studies suggest 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. (17) have demonstrated that total physical activity levels were similar between 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 (17, 35) have compared children who walk to school to those who drive to school and found greater physical activity during the time of the trip to school compared to those driven to school. However, total physical activity over the measurement period was not different between the walkers and non-walkers in all three of these studies.

Each of the prior studies reported mean data only, which assumes the relationships are constant across all individuals within each group and similar across each day of measurement. Our use of mixed models allowed us to examine the associations between inactivity and total physical activity and its components within each participant across each of the 6 days of measurement, which may account for the differences observed between studies.

We know that physical activity patterns are different on weekdays versus weekends in middle school girls (76) It may be that the structured nature of the typical school day does not allow the "activitystat" to produce compensatory changes in physical activity on weekdays. Perhaps during less structured weekend days there is opportunity for compensation to occur. However, 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 plays an important role in whether or not compensation occurs.

Energy expenditure calculations illustrate the impact of the associations we found. The mean energy cost of a brisk walk, considered to be at the low end of MVPA 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. Since every one-minute increase in MVPA is associated with a 1.85 minute decline in inactivity and a 0.85 minute increase in LPA, an intervention that increases MVPA by 5 minutes may result in an increase in energy expenditure of 82.7 kj/day (19.8 kcal/day). Although this may seem like a trivial change in energy expenditure, we have previously demonstrated that small increases in MVPA are associated with statistically significant decreases in percent body fat over a 2-year period in middle school girls (53).

There have been two experimental studies which have examined compensation in physical activity in youth. Dale et al. (28) 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. Blaak and colleagues (38) 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. Fifty percent of the increase in daily energy expenditure was attributed to the energy cost of the training program and the other 50% was explained by an increase in energy expenditure outside of training. Thus, there was an increase in non-exercise physical activity during the remainder of the day as measured by heart rate telemetry (38). Additional research that builds upon these types of studies are needed to advance our understanding of this issue.

The sample in the present study, although limited to girls, was larger and more ethnically diverse than previous related observational studies have reported. To our knowledge this is the first study to examine the associations with inactivity using accelerometry, an assessment method widely considered to be a more accurate measure of physical activity than self-report (63). Additionally, we used population specific accelerometer intensity cut points to quantify physical activity and inactivity.

This study provides valuable information on the within-girl relations between inactivity and total physical activity and its components over 6 days of objective measurement. Our data refute the existence of an “activitystat”, but suggest that increasing inactivity may displace MVPA. 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.

VII. CONCLUSIONS AND PUBLIC HEALTH IMPLICATIONS

A number of intervention studies have been developed to reduce the incidence of health risk factors in children and youth. Many of these studies have failed to produce favorable changes in physical activity (77, 78). While poor study design and methodological issues may very well explain the lack of an effect these interventions had on physical activity, an alternative explanation may be the existence of an “activitystat.” An “activitystat” is a biologically controlled regulatory mechanism for physical activity. Rowland (16) has hypothesized that energy expenditure, and thus physical activity, is physiologically regulated and that each individual has his/her own set-point physical activity level. Existence of such a biologically controlled compensatory phenomenon may help explain why some physical activity interventions have produced minimal changes in total physical activity levels.

We undertook two studies to explore the possibility of the existence of an “activitystat.” In the first study we found that both inactivity and physical activity tracked only to a modest degree. These findings suggest that over a two-year period there are substantial changes in rank within the population in physical activity and inactivity levels in adolescent girls. In the second study we found no associations between physical activity and inactivity which would suggest that compensatory relationship exists between these variables that would maintain a consistent level of total physical activity from day to day. Together these studies refute the existence of an “activitystat.” These findings suggest that middle school girls are not set in their physical activity and inactivity habits and that positive change in these behaviors may occur with proper intervention. By increasing MVPA in this age group inactivity may decrease and total physical activity may also increase. Likewise, decreasing inactivity could potentially result in increases in both MVPA and total physical activity.

Development of successful physical activity interventions in youth is dependent on the understanding of the details of their physical activity behavior, including the tracking of physical activity. Knowing the degree to which physical activity tracks provides insight as to when root determinants and early antecedents of this behavior occur. Few studies have assessed tracking of physical activity in middle school aged youth and none have examined the tracking of inactivity. This study provides tracking information for a period of life of great biological and social change using a method of measurement that is more accurate than that which has typically been used in the literature.

To date, physical activity research has largely relied upon self-report methods for the measurement of physical activity and inactivity. Previous studies of the association between inactivity and MVPA or total physical activity have found only very small and frequently insignificant relationships in the hypothesized direction for these variables. A validated method for assessing inactivity has not previously been used in these studies, instead specific sedentary behaviors, such as TV watching and video game playing have been used as proxy measures. In this dissertation we were able to measure both physical activity and inactivity objectively using population specific, validated intensity of activity thresholds. Use if this measurement instrument may account for the significant inverse relationships between these variables we found. This highlights the need for the development and use of more precise measurement tools for both physical activity and inactivity in epidemiologic research.

Use of TAAG data allowed use to conduct these studies in an observational manner and thus participants behaved in their usual activity habits. To test the existence of an "activitystat" may require a more clinical study design. It is possible that total physical activity may need to be elevated above a certain level in order to produce compensatory changes in physical activity and inactivity. Clinical studies comparing the effects of different exercise intensities on physical activity and inactivity levels outside of the exercise program may help address this issue. Incorporating more precise measures of both energy expenditure and physical activity into such studies may help to better understand the role and context of physical activity in total energy expenditure as it relates to the "activitystat". Our examination of the associations between physical activity and inactivity only included 6-days of measurement. A greater time between exposure to activity or inactivity may need to lapse before compensatory changes occur. Both observational and clinical studies with longer measurement periods are needed to further explore the "activitystat" hypothesis.

Given our lack of support for an "activitystat" other explanations for why many physical activity interventions do not produce positive results need to be addressed. Potential reasons include low participation rates, lack of statistical power, poor quality assurance/quality control, short duration of follow-up, inadequately adjusting for confounders, inappropriate statistical methodology, and as previously stated, use of imprecise measures of physical activity and inactivity. Given the current trends in the prevalence of childhood overweight and obesity, type 2 diabetes, and cardiovascular disease risk factors, there is a pressing need for physical activity interventions in children and youth that effectively reduce the risk of these health conditions. However, until a number of interventions have been carried out that address most, if not all, of the issues described it will be difficult to determine what factors contribute to the success or failure of physical activity interventions.

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