Light-Intensity Physical Activity Is Associated with Adiposity in Adolescent Females

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ABSTRACT

DOWD, K. P., D. M. HARRINGTON, A. HANNIGAN, and A. E. DONNELLY. Light-Intensity Physical Activity Is Associated with Adiposity in Adolescent Females. *Med. Sci. Sports Exerc.*, Vol. 46, No. 12, pp. 2295–2300, 2014. **Introduction**: Sedentary behavior (SB) research has relied on accelerometer thresholds to distinguish between sitting/lying time (SLT) and light-intensity physical activity (LIPA). Such methods may misclassify SLT, standing time (StT), and LIPA. This study examines the association between directly measured SB, physical activity (PA), and adiposity in an adolescent female sample. **Methods**: Female adolescents (n = 195; mean age, 15.7 yr (SD, 0.9)) had body mass index (BMI) (median, 21.7 kg·m^{-2} (interquartile range, 5.2 kg·m^{-2})) and four-site sum of skinfolds (median, 62.0 mm; interquartile range, 37.1 mm) measured and wore an activPAL™ activity monitor for 7 d. SLT, StT, breaks in SLT, and bouts of SLT <30 and ≥30 min were determined from activPAL outputs. A threshold of 2997 counts per 15 s determined moderate-to-vigorous PA. All remaining time was quantified as LIPA. Mixed linear regression models examined associations between PA variables, SB variables, and adiposity. **Results**: Participants spent a mean of 65.3% (SD, 7.1) of the waking day in SLT, 23.0% (SD, 5.3) in StT, 5.6% (SD, 1.5) in LIPA, and 6.1% (SD, 2.4) in moderate-to-vigorous PA. Significant effects for the percentage of LIPA (which excluded StT) with both BMI (β = −4.38, P = 0.0006) and sum of skinfolds (β = −4.05, P = 0.006) were identified. Significant effects for breaks in SLT with BMI (β = −0.30, P = 0.04) were also observed. No additional significant associations were found between activity measures and adiposity. **Conclusions**: Increased LIPA (excluding StT) and breaks in SLT were negatively associated with adiposity in this sample, independent of age. Interventional work should examine whether reducing SLT through breaks and increasing LIPA may prevent increases in adiposity in adolescent females.
Key Words: SEDENTARY, LIGHT PHYSICAL ACTIVITY, ACTIVPAL, OBESITY

A large and consistent body of evidence has shown that increased levels of physical activity (PA) protect children and adolescents from the development of overweight and obesity (9) and that moderate-to-vigorous PA (MVPA) is an independent predictor of adiposity in children and adolescents (24,28). To date, the majority of PA research has focused on MVPA (22). However, MVPA accounts for a very small proportion of total daily PA in youths, with data from the US National Health and Nutrition Examination Survey 2003–2004 identifying that objectively measured MVPA accounted for approximately 25 min·d^{-1} for 12- to 15-yr-old females and 20 min·d^{-1} for 15- to 19-yr-old females (29). It is now clear that the amount of energy expended through volitional exercise (e.g., MVPA) is not the dominant determinant of variability in daily energy expenditure in youths (12,13).

Nonexercise activity thermogenesis (NEAT) is described as the energy expended throughout activities of daily living and is composed of sitting/lying time (SLT), standing time (StT), and all light-intensity PA (LIPA) (15). There is increasing interest in the association between NEAT and indices of health in epidemiological studies. It has been hypothesized that components of NEAT have opposite associations with health outcomes, whereby SLT may be negatively associated with health outcomes, whereas StT and LIPA may be beneficial to health outcomes. It is through these activities at the lower end of the activity intensity spectrum that the majority of total daily energy is expended (15). However, it is not clear which components of NEAT are associated with health indices primarily because of limitations with existing measurement methodologies. The examination of the individual components of NEAT is extremely difficult because of the ubiquitous nature of such activities. The majority of research has used self-report measures to estimate time spent sedentary and in LIPA. Such measures have significant limitations because of recall difficulties and use of surrogate measures of sedentariness, such as television viewing time (1,16,22,26). More recent studies have used accelerometer-based activity monitors as a measure of sedentary time and LIPA (1,7,18,22). Although such devices

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have greater reliability and validity than those of self-report (16,21), these measures rely on the lack of ambulation rather than on postural position to estimate SLT. Consequently, this method of examining sedentary time often results in misclassification of StT and LIPA (6,23). This is a significant limitation because the behavior of sedentariness is defined as any "waking behavior spent in a sitting or reclining position that require an energy expenditure of <1.5 METs" (25) and consequently would not include StT.

Relations between objectively measured SLT, StT, LIPA, and indices of health in young people are poorly understood. Evidence in child and adolescent samples has found that associations between sedentary time and indices of health do not persist when controlling for MVPA (2,20), whereas no literature is currently available on the associations between objectively measured StT and indices of health. Similarly, limited information on the associations between LIPA and indices of health in young people is available, whereas no research has distinguished SLT from StT or StT from LIPA to provide a more comprehensive measure of both SLT and LIPA in any population.

The purpose of this study was to examine the associations between SLT, StT, and LIPA and adiposity in a sample of adolescent females using an inclinometer-based activity monitor.

METHODS AND PROCEDURES

Cross-sectional data were collected from a convenience sample of seven urban and six rural secondary schools in the midwestern region of Ireland between 2009 and 2011. Participants were randomly selected from a list of all 13- to 18-yr-old female students enrolled in each school. To be eligible for inclusion in this study, participants were required to have no injuries or illnesses that negatively affected their participation in PA. The numbers recruited from each school varied by school size. This study was reviewed and approved by the University of Limerick research ethics committee. A total of 216 students provided written informed participant and parental consent and participated in the full test days. Because of insufficient activity monitor data, 21 data sets were excluded from analysis. A total of 195 valid data sets were included in the present analysis.

Measurement of PA and sedentary behaviors. The inclinometer-based activity monitor used in this research was the activPAL™ professional PA monitor (PAL Technologies Ltd., Glasgow, United Kingdom). The characteristics of the activPAL™ have been described elsewhere (3). Briefly, the activPAL is a single-unit uniaxial accelerometer, measuring 53 × 35 × 7 mm and weighing approximately 15 g. The device was worn on the midpoint of the anterior aspect of the thigh and was attached to the skin using a hydrogel adhesive pad (PALstickie). For consistency, participants were instructed to wear the device on their right thigh only for a 7-d period. The device was worn for 24 $h \cdot d^{-1}$ throughout the measurement period and was only removed for bathing or for water-based activities. Proprietary algorithms classified the individual's free-living activities into SLT, StT, stepping time, step count, and activity counts. The activPAL communicates with a Windows-compatible PC (Microsoft Excel 2010; Microsoft Corp., One Microsoft Way, Redmond, WA) using a universal serial bus interface.

Measurement of adiposity. Height was measured to the nearest 0.25 cm using a portable wall stadiometer (Seca model 214; Seca Ltd., Birmingham, United Kingdom). Body weight was measured to the nearest 0.01 kg using a portable electronic scale (Seca model 77; Seca Ltd., Birmingham, United Kingdom). Body mass index (BMI) was calculated by dividing weight (kg) by height squared (m^2), and BMI percentiles were calculated on the basis of age and sex in accordance with the Centers for Disease Control and Prevention reference data (11). Skinfold measurements were obtained from four sites (biceps, triceps, subscapular, and iliac crest) according to the skinfold protocol of the International Society for the Advancement of Kinanthropometry (17). Skinfold thickness was measured to the nearest 0.25 cm using a Harpenden skinfold caliper (Cranlea & Co., Birmingham, United Kingdom). All anthropometric measures were obtained during a single visit to each school. Three trained investigators carried out the anthropometric measures. The intertester technical error of measurement was 10% for skinfold thickness, whereas the intratester technical error of measurement was set at 5% for skinfold thickness measures. If the technical error of measurements was greater than these values, a third measurement was taken and the median value was used for analysis.

Data processing. A 7-d measurement protocol, which provides a minimum of four valid days of activity data (including one weekend day), has been suggested as a valid recording duration for adolescent populations (30). For the purpose of this analysis, a valid day was classified as a measured day with ≤4 h of nonwear time during waking hours. Nonwear time was defined as a period with ≥60 min of consecutive zero activity counts. This method for identifying periods of nonwear is consistent with free-living data reduction methodologies (8). The nonwear periods for each day were summed, and all measurement days with ≥4 h of nonwear time during waking hours were removed. Participants that did not provide four valid days of activity monitoring data (including at least one weekend day) were removed from all further analysis (n = 21). For all remaining participants, the daily nonwear time was summed, and the measured waking day was adjusted accordingly.

All sedentary behavior (SB) and PA variables were presented as percentages of waking time. To estimate bed hours, the first registered nonsedentary epoch after 7:00 a.m. was identified as rise time. This time was chosen because manual prescreening of participants' rise times identified that no participants woke before 7:00 a.m. The last registered nonsedentary epoch, which was followed by an uninterrupted sedentary period (>2 h), was identified as the time the participants went to bed. The amount of waking time was then calculated as waking hours = bed time − rise time.

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TABLE 1. Descriptive characteristics of the sample (n = 195).

	Mean (SD)	Range
Age (yr)	15.7 (0.9)	13.1–18.7
BMI (kg·m^{-2})[a]	21.7 (5.2)	15.4–41.3
Sum of skinfolds (mm)[b]	62.0 (37.1)	26.6–207.1
SLT (%)	65.3 (7.1)	44.3–83.0
No. of breaks in SLT	59.7 (13.0)	32.0–106.4
Sitting/lying bouts <30 min (%)	34.8 (6.5)	8.7–49.9
Sitting/lying bouts >30 min (%)	30.5 (8.8)	6.0–57.6
StT (%)	23.0 (5.3)	10.6–41.0
LIPA (incl. standing) (%)	28.7 (6.1)	13.8–47.6
LIPA (excl. standing) (%)	5.6 (1.5)	2.5–11.2
MVPA (%)	6.1 (2.4)	1.6–13.6

%, variables are presented as percentages of the waking day.
[a]Data are presented as median (IQR), n = 194.
[b]Data are presented as median (IQR), n = 193.

Free-living PA and SB. The activPAL was used to estimate daily PA and SB variables, including SLT, breaks in SLT, SLT bouts of <30 min, SLT bouts of ≥30 min, StT, LIPA including StT (incl. StT), LIPA excluding StT (excl. StT), and MVPA. A detailed description of the methodologies used to examine these PA and SB variables has previously been reported (3). SLT was defined as all time spent in a sitting or lying posture and was calculated by summing the total number of seconds spent in sitting/lying postures over the waking measurement period. Breaks in SLT were defined as any transition from a sitting/lying posture to a standing posture, and breaks in SLT were summed over the waking measurement period. An SLT bout of <30 min is defined as the amount of time spent in a sitting/lying posture for <30 min, whereas an SLT bout of ≥30 min is defined as the amount of time spent in a sitting/lying posture for ≥30 min. The amounts of time spent in SLT bouts of <30 and ≥30 min were summed over the waking measurement period. StT was defined as all time spent in a standing position where no locomotion/stepping was achieved (e.g., standing still), LIPA was defined as all time spent in a locomotive/stepping behavior, which was at an intensity of <3 METs (e.g., slow walking, household chores, etc.), whereas MVPA was defined as all time spent in a locomotive/stepping behavior, which was at an intensity of ≥3 METs. For MVPA, a threshold of 2997 counts per epoch (15 s) was used to estimate METs for each 15-s period, where MVPA was defined as ≥3 METs (4). LIPA (excl. StT) was then calculated as follows: LIPA (excl. StT) = [24 h − (SLT + StT + MVPA)]. LIPA incl. StT was calculated as follows: LIPA (incl. StT) = StT + LIPA (excl. StT). SLT was adjusted by subtracting nonwear time from SLT. This method of examining nonwear time data was completed as 1) no records for the types of activity completed during nonwear time were collected and 2) nonwear time would otherwise be categorized as SLT. Total daily wear time was calculated by subtracting nonwear time from the waking measurement period, and each variable was then divided by the total daily waking wear time to derive the percentage of waking time spent in each PA and SB variable.

Statistical analysis. Descriptive statistics were calculated and are presented as mean (SD) for normally distributed variables or median (interquartile range (IQR)) for skewed distributions. The Spearman correlation coefficient (r_s) was used to measure the association between PA and SB variables and both BMI and sum of skinfolds. Mixed linear regression models were used to examine these relations after adjusting for age and the clustering of participants within schools. School was included as a random effect in the models, and age was included as a fixed effect. Separate models were fitted for each PA and SB variable as a predictor of outcomes (BMI and sum of skinfolds). Models that adjusted for MVPA were also fitted after testing for colinearity of MVPA with the other PA and SB variables. Residual analysis was used to check assumptions underlying the model, and model fit was assessed using the Akaike information criterion and Schwarz Bayesian information criterion. A 5% level of significance was used for all statistical tests. Statistical analyses were undertaken using IBM SPSS Statistics version 20 (IBM, Armonk, NY) and SAS version 9.2 (SAS Institute Inc., Cary, NC).

RESULTS

Descriptive statistics for the sample are presented in Table 1. A broad BMI range was observed (15.4–41.3 kg·m^{-2}). Nine participants (4.6%) were classified as underweight, 132 participants (67.7%) were classified as having normal weight, 41 participants (21.0%) were classified as overweight, and 13 participants (6.7%) were classified as obese. A total of 29 participants provided four valid days of accelerometer data (14.9%), with 140 participants providing five valid days (71.8%) and 26 participants providing six valid days (13.3%). Of all participants included in this analysis, 180 provided data on both weekend days (92.3%), with 15 participants providing data on one weekend day (7.7%). The average percentage of waking time spent in each activity variable was 65.3% for SLT, 23.0% for StT, 5.6% for LIPA, and 6.1% for MVPA. Of the daily waking hours, an average of 9.6 h (SD, 1.2) was spent in SLT, 3.4 h (SD, 0.8) in StT, 0.8 h (SD, 0.2) in LIPA, and 0.9 h (SD, 0.4) in MVPA. When examined together, LIPA (incl. StT) accounted for 28.7%, or 1.7 h (SD, 0.5), of the waking measurement period.

Of all PA and SB variables examined, the percentage of waking time spent in LIPA (excl. StT) had the strongest association with BMI percentile and sum of skinfolds (Table 2). A weak-to-moderate negative association was found between increasing LIPA (excl. StT) and both BMI percentile ($r_s = -0.24$, $P < 0.001$) and Σ skinfolds ($r_s = -0.25$, $P < 0.001$).

TABLE 2. Correlations between PA and SB variables and measures of adiposity (n = 195).

	BMI Percentiles[a]		Σ Skinfolds	
	r_s	P Value	r_s	P Value
SLT (%)	0.15	0.04	0.18	0.01
No. of breaks in SLT	−0.10	0.18	−0.11	0.14
Sitting/lying bouts <30 min (%)	0.01	0.90	0.04	0.58
Sitting/lying bouts >30 min (%)	0.10	0.16	0.10	0.18
StT (%)	−0.10	0.17	−0.13	0.08
LIPA (incl. standing) (%)	−0.15	0.03	−0.17	0.02
LIPA (excl. standing) (%)	−0.24	0.001	−0.25	0.001
MVPA (%)	−0.04	0.57	−0.10	0.15

%, variables are presented as a percentage of the waking day.
[a]n = 194.

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The association between percentage of waking time spent in LIPA (excl. StT) and both BMI percentile ($\beta = -4.38$, $P = 0.0006$) and sum of skinfolds ($\beta = -4.05$, $P = 0.006$) was significant after adjusting for age and clustering of participants in schools (Table 3). The negative parameter estimate for β suggests an inverse relation between increasing LIPA (excl. StT) and excess adiposity. A significant association was also observed between the number of breaks in SLT and BMI percentiles ($\beta = -0.30$, $P = 0.04$), but not sum of skinfolds ($\beta = -0.30$, $P = 0.07$), after adjustment for age and school clustering. No additional significant association was observed between SLT, SLT bouts of <30 min, SLT bouts of ≥30 min, StT, LIPA (incl. StT) or MVPA, and measures of adiposity after adjusting for age and school clustering (Table 3). Adjusting for MVPA in models, which included the other PA and SB variables, did not improve the fit or change the conclusions from the models (results not shown).

DISCUSSION

This study examined the associations between the percentage of waking time spent in SLT, breaks in SLT, percentage of waking time spent in SLT bouts <30 and ≥30 min, StT, LIPA (both incl. and excl. StT), and body composition measures in a sample of adolescent females using an inclinometer-based activity monitor. The use of this monitor allows the novel examination of StT as a separate activity variable from SLT and LIPA, which has not been possible using alternative monitors. Of all the PA and SB variables measured in this study, LIPA (excl. StT) was identified as having the strongest association with both BMI percentiles and sum of skinfold thickness. These associations were independent of age. The number of breaks in SLT was also significantly associated with BMI percentiles after adjustment for age. The association between breaks in SLT and BMI percentile indicates that replacing SLT with other activities is beneficial for BMI. This association mirrors the stronger association between LIPA and BMI percentiles. Together, these associations suggest that breaking SLT and replacing it with LIPA is associated with a reduced BMI percentile. No additional significant associations were evident between PA and SB variables (including MVPA) and measures of body composition in this sample after adjusting for age.

The findings of this study have public health significance. The dramatic increase in the prevalence of overweight and obesity in developed nations has prompted great interest in developing alternative approaches to increase daily energy expenditure in sedentary lifestyles, including increasing the amount of time spent in StT (14). However, a recent examination of the energy expended during StT compared with that during SLT has identified that minimal differences in energy expenditure exist (<20 $\text{kcal}\cdot\text{d}^{-1}$) (19). These findings may help explain the results of this study. Although a large proportion of waking time was spent in a standing posture (23.0%), the amount of energy expended because of standing may not be sufficient to positively affect body composition in this adolescent female sample. In addition, when StT was included with LIPA (excl. StT), the behavior seems to mask the effect of LIPA (excl. StT) on measures of body composition. This study suggests that interventions, which target increasing LIPA (excl. StT) (i.e., ambulation at an intensity of <3 METs) through reducing SLT and StT, may change adiposity in an adolescent female population. It is important to note that the postural change from sitting to standing may have additional health benefits in relation to the breaking of prolonged sedentary time, but in this sample, StT, LIPA (incl. StT), or SLT bout duration was not associated with body composition measures.

Placing these findings among existing research is extremely difficult primarily because of the lack of accurate information on objectively determined LIPA in child and adolescent samples. The predominant reason for this dearth of information is difficulties in detecting and assessing this specific activity behavior (26). Of the limited evidence on the associations between LIPA and adiposity in adolescent populations, the results are contrasting in nature (5,27). Ekelund et al. (5) identified no association between accelerometer-determined LIPA (Manufacturing Technology Inc. activity monitor) and body fatness in 1292 European children 9–10 yr old without adjusting for additional activity variables (e.g., SLT or MVPA). In contrast, Steele et al. (27) identified a weak but significant linear relation between accelerometer-determined LIPA (ActiGraph GT1M activity monitor) and BMI after adjustment for a range of covariates including SLT. Differences observed across studies

TABLE 3. Association between PA and SB variables and measures of adiposity (n = 195).

	Outcome: BMI Percentile[a]		Outcome: Σ Skinfold	
	β (95% CI)	P	β (95% CI)	P
SLT (%)	0.51 (−0.01 to 1.04)	0.06	0.43 (−0.18 to 1.03)	0.17
No. of breaks in SLT	−0.30 (−0.59 to 0.01)	0.04	−0.30 (−0.63 to 0.03)	0.07
Sitting/lying bouts <30 min (%)	0.06 (−0.51 to 0.64)	0.83	0.11 (−0.56 to 0.77)	0.76
Sitting/lying bouts >30 min (%)	0.31 (−0.12 to 0.74)	0.16	0.22 (−0.27 to 0.71)	0.37
StT (%)	−0.43 (−1.14 to 0.28)	0.23	−0.20 (−1.02 to 0.63)	0.64
LIPA (incl. standing) (%)	−0.57 (−1.17 to 0.04)	0.07	−0.38 (−1.08 to 0.33)	0.29
LIPA (excl. standing) (%)	−4.38 (−6.87 to 1.90)	0.0006	−4.05 (−6.94 to 1.16)	0.006
MVPA (%)	−0.77 (−2.35 to 0.81)	0.34	−1.31 (−3.13 to 0.52)	0.16

Separate linear mixed models for each PA and SB variable, with school as a random effect for BMI percentile; separate linear mixed models for each PA and SB variable, with school as a random effect and age as a fixed effect for sum of skinfolds.
[a] n = 194.
Σ skinfold, sum of four skinfold measurements; CI, confidence interval.

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might be due to the inclusion of different covariates in the regression models, yet it is more likely due to the use of different sedentary thresholds, which results in significant differences in the amount of quantified LIPA (10). As identified by Ridgers et al. (23), significant differences in accelerometer-determined SLT can be observed using sedentary thresholds, which differ greatly. In addition, such accelerometer-based activity monitors have been shown to consistently and significantly overestimate sitting and walking activities primarily because of their inability to examine StT and, consequently, may have misquantified LIPA through misclassifying StT as SLT or as LIPA (4,6). Through the use of an inclinometer-based activity monitor, which accurately and reliably distinguishes between SLT and StT, this study has provided valid and reliable estimates of SLT, StT, and LIPA and has examined the associations between these PA and SB variables and adiposity.

The findings of this study have identified that SLT is not associated with body composition after adjustment for age. The associations between SLT and body composition in this article are consistent with existing examinations of the relation between accelerometer-determined SLT (which have corrected for MVPA) and cardiovascular risk factors in child and adolescent samples (2), but the present findings are based on SLT determined from an inclinometer-based activity monitor. Previous objective examinations have used accelerometer-based activity monitors (e.g., ActiGraph GT1M and GT3X) as measures of PA and have estimated SLT using an activity count threshold (e.g., <100 cpm). This method estimates SLT on the basis of lack of ambulation (23). In contrast, the present study has used an activity monitor, the activPAL™, which directly measures SLT through the inclination of the thigh. Significant differences have been observed between ActiGraph- and activPAL-determined SLT, with the activPAL demonstrating increased accuracy at measuring SB (6,10). Furthermore, the use of the activPAL has been encouraged in studies that aim to examine specific sedentary patterns and behaviors (1), whereas it has been used as the reference measure for the objective examination of SB when validating accelerometer-based activity monitors (6,23).

The findings presented here suggest that activities at the lower end of the PA continuum have an influence on health outcomes in adolescent females and that increasing LIPA at the expense of SLT and StT may be of great benefit in the maintenance of a healthy weight profile in this population. Additional cross-sectional research is required to examine whether these associations are evident across all populations, including children, male adolescents, and adults of all ages, whereas longitudinal and interventional evidence is necessary to determine the effects of reduced SLT through increased LIPA on adiposity and additional cardiovascular risk factors in all populations.

Limitations to this analysis include the cross-sectional design that represents a relatively small sample of adolescent females in one geographical area over a 2-yr period and may not be representative of all populations. We did not measure additional covariates, such as stage of pubertal development, nutritional information, socioeconomic status, urban/rural dwelling, and smoking, to include in the models. Strengths of this study should be noted. To our knowledge, this is the first study to present relations between the full range of objectively determined PA intensities and directly measured SB with adiposity in any population.

In summary, these observations have identified associations between LIPA (excl. StT) and body composition measures in an adolescent female population. The results of this study suggest that increasing LIPA (excl. StT) (e.g., slow walking, household chores, etc.) at the expense of SLT and StT could be a worthwhile initiative for weight management in an adolescent female population. Future interventional research should focus on whether decreasing total SLT through breaks and increasing LIPA may prevent unhealthy increases in adiposity in adolescent females. Further research is also required to examine and interpret the associations between breaks in SLT and body composition in adolescent females.

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