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The Development of Activity Profiles in Adolescent Females and their Association with Adiposity

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Objectives: This study aims to (1) use the objective activPAL activity monitor to assess physical activity behaviors, including sitting/lying, standing, and both light (LIPA) and moderate-to-vigorous physical activity (MVPA); (2) to develop distinct activity profiles based on time spent in each behavior in a sample of adolescent females; and (3) examine whether levels of adiposity differ across these activity profiles. ***Methods:*** Female adolescents (n = 195; 14–18 y) had body mass index (median = 21.7 [IQR = 5.2] kg/m^2) and 4-site skinfold thickness (median 62.0 mm; IQR = 37.1) measured. Physical activity behaviors were measured using the activPAL. Hierarchical cluster analysis grouped participants into activity profiles based on similar physical activity characteristics. Linear mixed models explored differences in body composition across activity profiles. ***Results:*** Three activity profiles were identified, a low (n = 35), moderate (n = 110), and a high activity profile (n = 50). Significant differences across activity profiles were observed for skinfold thickness (p = .046), with higher values observed in the low activity profile compared with the high activity profile. ***Conclusions:*** Profiling free-living activity using behaviors from across the activity intensity continuum may account for more of the variability in energy expenditure then examining specific activity intensities, such as MVPA alone. The use of activity profiles may enable the identification of individuals with unhealthy activity behaviors, leading to the development and implementation of more targeted interventions.

Keywords: sitting behavior, physical activity, activPAL, cluster analysis, activity profile, adolescents, obesity

Levels of childhood overweight and obesity are at epidemic proportions (43), with 43 million children estimated to be overweight or obese globally (5). Approximately 25% of European adolescents are overweight or obesity (22), while 16.9% of 2–19-year-olds in the United States are now considered obese (28). Overweight and obese children are at a significantly increased risk of becoming overweight and obese adults (34,37) and of developing a range of health consequences, including type 2 diabetes mellitus, cardiovascular disease in adulthood, and site-specific cancers (10).

Population-based research has traditionally focused on examining the effects of moderate-to-vigorous physical activity (MVPA) on cardiovascular risk factors, including measures of adiposity (2,29). More recently, sedentary time (referred to as any waking behavior spent in a sitting/reclining position requiring an energy expenditure of ≤ 1.5 metabolic equivalents [38]) has also been identified as having an important role in the development of risk factors for cardiovascular disease in adults (29). The predominant method of examining associations between these physical activity behaviors, such as sedentary time or MVPA, and indices of health has been to focus on the specific behavior (i.e., sitting/lying time) while adjusting for some confounding variables (i.e., MVPA) (2). This method overlooks additional behaviors, such as standing time and light intensity physical activity (LIPA), which are influential in energy expenditure and subsequent weight management (1,25,35). Standing time has been suggested as a behavior which increases energy expenditure (19), and that increasing the amount of time spent in this behavior has the potential to positively impact levels of adiposity in adults (18), while activities of daily living account for the majority of daily energy expenditure (20) and may also play an important role in weight management and the prevention of cardiovascular disease in adults (11,12). Recent evidence has highlighted that levels of LIPA, and not sedentary time or MVPA, are associated with adiposity in a sample of adolescent females (8). Furthermore, interventions aimed at modifying physical activity energy expenditure through standing or LIPA may be more successful than those targeting MVPA only (35). Collectively, this evidence suggests that physical activity behaviors across the activity intensity continuum play an important role in the development of overweight/obesity and cardiovascular disease.

Physical activity plays a critical role in weight management in child and adolescent populations (14,36). Increased participation in physical activity in youth is protective against both the development of overweight and obesity in childhood (15) and in adulthood (44). Levels of physical activity track moderately well from childhood and adolescence through to adulthood, meaning less active and more sedentary adolescents are likely to remain less active and more sedentary into adulthood (37). The prevalence of child and adolescent populations achieving the recommended amount of daily physical activity is low, with approximately 57% of male and 28% of female European adolescents achieving the recommendations (32). In the United States, these figures are lower, with 42% of 6–11-year-old children achieving the recommendations, falling to only 8% of 12–19-year-olds (40). Adolescent females are significantly less active and more sedentary than their male counterparts, while physical activity decreases throughout adolescence at a greater rate in females than in males (26,32,40). This has public health significance, as the prevalence of cardiovascular risk factors in adult females is on the increase, with cardiovascular disease the cause of 1 in 2.8 deaths in adult females, compared with 1 in 4.5 for cancer (21).

Although evidence supports the deleterious effects of sedentary time on indices of health (12), this evidence has relied heavily on surrogate measures such as self-reported screen time and sedentary thresholds rather than direct measures of sitting/lying time, while little evidence is available on the relationship between standing time and indices of health. Developments in objective activity monitoring have enabled the accurate examination of sitting/lying time and standing time through examining postural position. Such devices also enable the estimation of LIPA and MVPA through the use of developed activity intensity thresholds (8). Although the use of activity intensity thresholds have limitations with categorizing specific types of activities (i.e., carrying loads and other high-intensity nonambulatory activities), their use is widely employed in population-based research (30,46). The resulting activity information (sitting/lying time, standing time, LIPA, and MVPA) can be used together to describe an individual's activity profile. Cluster analysis is a multivariate statistical technique which aims to group individuals so that individuals in the same group or cluster are more similar to each other (across selected characteristics) than they are to those in other clusters (9). The development of clusters or profiles across multiple objectively measured physical activity behaviors and examining the associations between these activity profiles and indices of health may prove a worthwhile method of identifying at-risk populations, as this method takes into account physical activity behaviors from across the activity intensity continuum, potentially explaining more of the variability in free-living activity energy expenditure and highlighting individuals with at-risk activity profiles that may otherwise be missed (i.e., those with an average amount of MVPA, low levels of standing time, low levels of LIPA, and high levels of sitting/lying time).

The aims of this study are to (1) record the spectrum of objectively assessed components of physical activity behaviors (sitting/lying time, standing time, LIPA, and MVPA), (2) develop distinct activity profiles within a sample of adolescent females, and (3) determine whether differences in measures of adiposity exist across the identified activity profiles. The long-term motivation of this research is to provide an evidence base for more targeted intervention strategies to increase physical activity profiles of adolescent females.

Methods

Participants

All procedures were approved by the University of Limerick and the University Hospital Limerick research ethics committees. Cross-sectional data were collected from participants in a convenience sample of 13 schools in the Midwestern region of Ireland between 2009 and 2011. Participants were randomly selected from a list of all 13–18-year-old female students in each school. To be eligible for inclusion, participants were required to have no self-reported physical disabilities, injuries, or illnesses which impact their participation in physical activity. A total of 390 students were randomly selected to participate in the study, of which 76% returned completed parental and participant consent to take part in the study. All adolescent females that provided both parental and participant consent were asked to wear an activity monitor for 7 consecutive days and to have anthropometric measurements taken. Absence from school on test days, extracurricular activities on test days, or decision to withdraw assent resulted in a total of 216 adolescent females participating in this study.

Measurement of Physical Activity Behaviors

Physical activity behaviors were examined using the activPAL professional physical activity monitor (PAL Technologies Ltd, Glasgow, UK). The activPAL is a valid and reliable measure of sitting/lying time, standing time, and MVPA in youths (3,7). A detailed description of the activPAL and the wear protocol have been described elsewhere (7). The activPAL was worn on the anterior aspect of the midline of the right thigh. All participants were instructed to wear the device for 7 days. The device was worn for 24 h/day throughout the measurement period, and was only removed for bathing or other water-based activities. Activity data were stored in 15-second epochs. Proprietary algorithms classify free-living activities into sitting/lying time, standing time, stepping time, step count, and activity counts.

Data processing for the activPAL output have previously been described (6). Briefly, for data to be included in this analysis, a minimum of 4 valid days of accelerometer measurement (including one weekend day) were required (41). For the purpose of this analysis, a valid day was classified as a measured day with < 4 hours of nonwear time during waking hours. Physical activity behaviors (sitting/lying time, standing time, LIPA, and MVPA) were presented as a percentage of waking time. The first registered nonsedentary epoch after 7 a.m. was identified as "rise time", as manual prescreening of participants identified no participants woke before 7 a.m. The last registered nonsedentary epoch followed by an uninterrupted sedentary period (> 2 h) was identified as the participant's "bed time". Waking hours was calculated as: waking hours = bed time – rise time. Sitting/lying time and standing time were determined through postural position using the activPAL. MVPA was examined using a validated count to activity thresholds of 2997 counts/15-s epoch from the activPAL accelerometer count function (7). MVPA corresponded to activities which required an intensity of > 3 metabolic equivalents. LIPA was calculated as, waking hours – (sitting/lying time + standing time + MVPA), and corresponded to all activities (i.e., slow walking, doing chores, etc.) which were not sitting/lying time, standing time, or MVPA. Total daily accelerometer counts were also computed by summing the number of accelerometer counts accumulated throughout the measured day.

Measurement of Body Composition

Height was measured to the nearest 0.25 cm using a portable stadiometer (Seca model 214, Seca Ltd., Birmingham, UK). Body weight was measured to the nearest 0.1 kg using a portable electronic scale (Seca model 770, Seca Ltd., Birmingham, UK) following standard procedures. Body mass index (BMI) was calculated as (weight in kg/[height in m]^2) and converted to percentiles based on the Centers for Disease Control and Prevention (CDC) reference data (17). Skinfold measurements were obtained from 4 sites (bicep, triceps, subscapular, iliac crest) according to the skinfold protocol of the International Society for the Advancement of Kinanthropometry (24). Skinfold thickness was measured using a Harpenden skinfold caliper (Cranlea & Co, Birmingham, UK). Three trained investigators carried out the anthropometric measures. For skinfold thickness measures, intertester and intratester technical error of measurement was set at < 10% and < 5%, respectively. If technical error of measurements was greater than these values, a third measure was taken and the median value was used (23).

Statistical Analysis

Descriptive statistics were calculated and are presented as mean (*SD*), median (interquartile range), or percentages. All numeric variables were examined for normality using formal tests of normality, skewness, and kurtosis statistics and through visual inspection of histograms.

Hierarchical cluster analysis was carried out to identify groups of adolescents with similar characteristics of physical activity behaviors. Ward's method was used as the clustering method and the squared Euclidean distance was the measure of distance. The optimum number of clusters was identified using visual inspection of the dendrogram, rescaled distances in the dendrogram, and measures such as the semipartial R^2 and R^2. The final solution was selected based on conceptual interpretation and maximizing variability between clusters.

A one-way ANOVA with post hoc pairwise comparisons using a Bonferroni correction was performed to examine whether age differed across activity profiles. Linear mixed regression models were used to examine differences in physical activity behaviors and adiposity measures across activity profiles after adjusting for age and the clustering of participants within schools. School was included as a random effect in the models; age and cluster membership were included as fixed effects. Residual analysis was used to check assumptions underlying the model, and model fit was assessed using Akaike's Information Criterion (AIC) and Schwarz's Bayesian Information Criterion (BIC). A 5% level of significance was used for all statistical tests. Statistical analyses were undertaken using IBM SPSS Statistics v. 20 (Armonk, NY) and SAS version 9.2 (SAS Institute Inc., Cary, NC).

Results

The mean age of the sample was 15.7 (*SD* = 0.9) years. The median BMI of the sample was 21.7 (IQR 5.2) with a BMI range of 15.4–41.3 kg/m^2. A total of 9 participants (4.6%) were classified as underweight, 132 participants (67.7%) as normal weight, 41 participants (21.0%) as overweight, and 13 participants (6.7%) as obese. Of the 216 participants recruited, 21 sets of participant data were removed due to insufficient activity information, resulting in a total of 195 valid datasets included for analysis. Of the 195 datasets included, 14.9% (*n* = 29) provided 4 valid days, 71.8% (*n* = 140) provided 5 valid days, and 13.3% (*n* = 26) provided 6 valid days of data. Descriptive statistics for body composition measures and physical activity behaviors are presented in Table 1.

\insert Table 1

The cluster analysis of physical activity behaviors (based on sitting/lying time, standing time, LIPA, and MVPA) identified 3 distinct activity profiles with an R^2 of 70.4% and a cubic clustering criterion of 5.2, indicating a good clustering solution. Activity profiles were defined as low (least favorable activity profile characterized by low standing time, LIPA, and MVPA, and high sitting/lying time), moderate (moderate activity profile characterized by moderate levels of sitting/lying time, standing time, LIPA, and MVPA) and high (most favorable activity profile characterized by high standing time, LIPA, and MVPA, and low sitting/lying time). Overall, 35 participants (18.0%) were grouped into the low activity profile, 110 participants (56.4%) into the moderate activity profile, and 50 participants (25.6%) into the high activity profile. Descriptive statistics for body composition measures and physical activity behaviors across activity profiles are presented in Table 2.

\insert Table 2

Differences in mean age across activity profiles were significant using ANOVA (p = .03). Linear mixed models examined differences in the physical activity behaviors and body composition measures across activity profiles, after adjusting for age as fixed effect and school as a random effect (Table 2). Physical activity behaviors were significantly different across activity profiles (p < .001). Analysis of skinfold thickness across activity profiles identified differences to be significant (p = .046), with the high activity profile having lower median skinfold thickness than the low activity profile. No significant differences were observed across activity profiles for BMI percentiles.

Discussion

To our knowledge, this is the first study to use cluster analysis to group a sample of adolescent females into activity profiles based on objectively measured physical activity behaviors across the entire activity intensity continuum. Three activity profiles, determined by sedentary time, standing time, LIPA, and MVPA, were identified in this sample, with physical activity behaviors differing significantly across each profile. The results of this analysis identified significant differences for skinfold thickness across activity profiles in this sample, with higher skinfold thickness observed in the low activity profile compared with the high activity profile.

The methods employed in this paper are unique, grouping individuals based on objectively determined data from all physical activity behaviors, rather than focusing on a single individual component of physical activity, such as sedentary time or MVPA. A small number of published studies have grouped youths using cluster analysis. The majority of these studies have clustered based on self-reported participation in specific activities such as skateboarding and participation in individual sports (qualitative data) (27,39), rather than clustering on time spent in specific postures or physical activity intensities (quantitative data). Their findings, therefore, are not comparable to the findings presented here using objective data. One study clustered youths into specific activity profiles based on self-reported participation in specific physical activities (i.e., traditional sports, fitness activities), self-reported time spent in specific sedentary activities (i.e., TV viewing), and accelerometer-determined MVPA (13). The results identified 3 distinct activity profiles (active = 18.7%, moderate = 33.7%, and sedentary = 47.6%), similar to the findings presented in this paper. Although the authors included an objective measure of MVPA in their cluster analysis of physical activity behaviors, the inherent limitations of self-reported ubiquitous behaviors, such as sedentary time, remain (33).

One study, to our knowledge, has previously used objective accelerometry to determine clusters based on sedentary time and MVPA (4), identifying 4 distinct groups. The study highlighted that the cluster with the most preferable activity profile (high MVPA, low sedentary time) had significantly lower BMI, waist circumference, and percentage of overweight compared with the remaining clusters in a cohort of 10–12-year-old European children (4). A limitation of this study was the use of the "lack of ambulation" as an estimate of sedentary time (31), while the absence of activity behaviors which account for the majority of daily energy expenditure (i.e., standing time and LIPA) may mask additional associations between different clusters. The use of an objective and valid activity monitor to determine all major components of physical activity behaviors, as presented in the current study, will increase the accuracy in classifying individuals into distinct activity profiles based on energy expended through activities of daily living. For example, although an individual may accumulate a relatively high amount of sedentary time and a low amount of MVPA compared with their peers, they may also accumulate high amounts of standing time and LIPA. Based on MVPA and sedentary time alone, this individual may have a relatively “unhealthy” activity profile, while other behaviors that account for a significant amount of daily energy expenditure (i.e., LIPA and standing time) are not taken into account. When participants in this sample were split into tertiles of both MVPA and total daily activity counts, no patterns for BMI percentiles or skinfolds were observed across tertiles (data not shown, available from the authors). However, when additional behaviors such as standing time and LIPA are considered, the overall profile categorizes individuals based on physical activity behavior characteristics from across the activity intensity continuum, and highlights differences in body composition across profiles.

The findings of this study highlight that adolescent females in the low activity profile have significantly higher median skinfold thickness than those in the high activity profile. The observed differences in skinfold thickness between the low and high activity profile may have important implications for design and implementation of targeted obesity interventions. Interventions during childhood/adolescence are suggested to modify behavior for lifelong physical activity in an effort to reduce the risk of associated diseases throughout the lifespan (42). Previous interventions that have focused solely on increasing levels of MVPA have had limited success (16,45). A potential alternative to this may be the modification of nontraditional components of physical activity behaviors, such as standing time and LIPA, in an effort to gradually increase levels of MVPA (35). It has been proposed that a sustained increase in the amount of time spent standing and in LIPA can increase energy expenditure enough to significantly impact adiposity (20,35). Through applying more targeted intervention strategies, which encourage a reduction in sitting/lying time by increasing standing time, LIPA, and MVPA, adolescent females could move to a more favorable activity profile.

The methodologies applied in this study have relevance to the wider population. Physical activity and sedentary behaviors across the intensity continuum influence energy expenditure and subsequent weight gain, particularly in adult populations (35). Through applying methodologies used in this study, researchers may identify specific groups in greatest need of intervention based on all components of physical activity and sedentary behaviors, rather than on the absence of MVPA. Such interventions may allow a more targeted strategy to simultaneously alter sitting/lying time, standing time, and LIPA, rather than solely focusing on modifying MVPA, a strategy that has previously been shown to have little or no success (35,45).

The strengths of this study should be noted. To our knowledge, this is the first time a valid and reliable activity monitor has been used to objectively determine physical activity and sedentary behavior when identifying activity profiles in any population. This is also the first study that has compared differences in health measures across such activity profiles. Despite these strengths, this study has limitations. The categorization of MVPA in this study relied on activity intensity cut-points, which have limitations when determining specific types of activities, including high intensity static activities and weight bearing activities (30). This is a relatively small sample of adolescent females, while the absence of additional covariates, including maturation and nutritional information, is also a limiting factor. The cross-sectional design of this study does not allow causal inferences to be made. It should be acknowledged that the variables used in this analysis, i.e., percentage of total or waking time spent in physical activity behaviors, represent compositional data in that their sum is constrained. Other measures of distance used in the cluster analysis may be useful for this type of data (i.e., Aitchison’s measure).

Conclusion

This study outlines and describes the methodologies employed to cluster a sample of adolescent females into activity profiles based on objectively determined physical activity behaviors. We present evidence that adolescent females who achieve lower levels of sedentary time and higher levels of standing time, LIPA, and MVPA have significantly lower levels of adiposity, measured by skinfold thickness, than their more sedentary and less active peers. This study describes association and not causation, suggesting that further research is warranted. However, at a population level, targeted interventions could explore whether modifying sitting/lying time, standing time, LIPA, and MVPA collectively in specific at-risk activity profiles has a beneficial effect on adiposity in adolescent females.

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Table 1 Descriptive Characteristics of the Sample (n = 195)

Characteristics	Mean (*SD*)	Range
Age (y)	15.7 (0.9)	13.1–18.7
Height (m)	1.64 (0.06)	1.46–1.82
[a]Weight (kg)	58.7 (15.6)	40.7–115.1
[a]Body mass index (kg/m^2)	21.7 (5.2)	15.4–41.3
[b]Body mass index percentile	68.2 (41.3)	1.0–99.0
[b]Sum of skinfolds (mm)	62.0 (37.1)	26.6–207.1
Sitting/lying (h)	9.6 (1.2)	6.2–12.9
Standing time (h)	3.4 (0.8)	1.6–6.3
Light intensity physical activity (excl. standing time) (h)	0.8 (0.2)	0.3–1.7
Moderate to vigorous intensity physical activity (h)	0.9 (0.3)	0.3–2.0
Sitting/lying (%)	65.4 (7.1)	44.3–83.0
Standing time (%)	22.9 (5.3)	10.6–41.0
Light intensity physical activity (excl. standing time) (%)	5.6 (1.5)	2.5–11.2
Moderate to vigorous intensity physical activity (%)	6.1 (2.4)	1.6–13.6

[a] Median (IQR); n = 194.

[b] Median (IQR).

% Percentage of waking time spent in physical activity behaviors; h = number of waking hours spent in physical activity behaviors.

Table 2 Descriptive Statistics for Age, Body Composition Measures, Physical Activity, and Sedentary Variables Across Activity Profiles

	Low (n = 35)		Moderate (n = 110)		High (n = 50)		p-value[a]
Age (y)	15.7 (1.12)		15.6 (0.86)		16.0 (0.75)		.03[c]
[b]Body mass index percentiles	75.0 (40.8)		69.0 (41.0)		63.5 (49.6)		.14
[b]Sum of skinfolds (mm)	70.6 (36.7)		59.5 (34.8)		56.7 (33.1)		.046
Total activity counts (daily)	1479652 (424901)		1921192 (510831)		2147884 (525182)		< .001
	%	Hours	%	Hours	%	Hours	
Waking hours		14.6 (1.0)		14.7 (0.7)		14.6 (0.8)	.52
Sitting/lying	75.6 (2.8)	11.0 (0.8)	66.1 (3.4)	9.7 (0.7)	56.8 (4.1)	8.3 (0.8)	< .001
Standing time	15.6 (2.0)	2.3 (0.3)	22.3 (2.4)	3.3 (0.4)	29.5 (3.4)	4.3 (0.5)	< .001
LIPA (excl. standing time)	4.2 (0.9)	0.6 (0.1)	5.5 (1.2)	0.8 (0.2)	6.8 (1.5)	1.0 (0.2)	< .001
MVPA	4.6 (1.9)	0.7 (0.3)	6.2 (2.3)	0.9 (0.2)	7.0 (2.5)	1.0 (0.4)	< .001

Abbreviations: LIPA = light intensity physical activity; MVPA = moderate-to-vigorous physical activity.

[a] p-value for age from ANOVA; p-value for percentage of total activity counts, waking time variables, and body composition measures from model adjusting for age and activity profiles as fixed effects and school as a random effect.

[b] Median (IQR); all other results presented as Mean (*SD*).

[c] Significant age difference between the low and high activity groups (Bonferroni adjusted p = .026).

% Percentage of time spent in specific physical activity behaviors; Hours = number of hours spent in specific physical activity behaviors.

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