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Latent profile analysis of young adolescents' physical activity across locations on schooldays

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Abstract

Purpose—To investigate whether adolescents cluster into profiles based on where they accumulate moderate-to-vigorous physical activity (MVPA), if overall MVPA differs across profiles, and if walking to school and participant and neighborhood characteristics explain profile membership.

Methods—Adolescents (N=528; mean age=14.12±1.44; 50% girls) wore accelerometers and Global Positioning Systems (GPS) trackers for 3.9±1.5 days to assess MVPA minutes in five locations: at home, at school, in home neighborhood, in school neighborhood, and other. Walking to school and participant characteristics were assessed by questionnaire, and neighborhood environment by Geographic Information Systems (GIS). Latent profile analysis (LPA) was used to identify profiles/groups of participants based on accumulation of physical activity across the five

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Conflict of interest

None

locations. Mixed-effects regression tested differences in overall MVPA, walking to school, and other characteristics across profiles.

Results—Four initial profiles emerged: one Insufficiently Active profile and three "Active" profiles (Active Around School, Active Home Neighborhood, and Active Other Locations). The Insufficiently Active profile emerging from the first LPA (90% of participants) was further separated into four profiles in a second LPA: Insufficiently Active, and three additional "Active" profiles (Moderately-Active Around School, Moderately-Active Home Neighborhood, and Active At Home). Those in the six Active profiles had more overall MVPA (41.1–92.7 minutes/day) than those in the two Insufficiently Active profiles (34.5–38.3 minutes/day). Variables that differed across profiles included walking to school, sports/athletic ability, and neighborhood walkability.

Conclusions—Although most participants did not meet the MVPA guideline, the six Active profiles showed the places in which many adolescents were able to achieve the 60-minute/day guideline. The home and school neighborhood (partly through walking to school), "other" locations, and to a lesser extent the home, appeared to be key sources for physical activity that distinguished active from insufficiently active adolescents. Finding the right match between the individual and physical activity source/location may be a promising strategy for increasing active travel and MVPA in adolescents.

Keywords

accelerometry; built environment; global positioning systems

1. INTRODUCTION

Because of the numerous physical and psychosocial health benefits of physical activity (Booth et al., 2012; Strong et al., 2005; Vaisto et al., 2014), the U.S. Department of Health and Human Services recommends that all children and adolescents achieve 60 minutes of moderate-vigorous physical activity (MVPA) per day (eDpartment of Health and Human Services, 2008). Adolescence marks a time of significant concern for inactivity, as research with objective measures suggests that only about 8% of adolescents meet the MVPA guidelines (Troiano et al., 2008). Additional research is needed to better understand MVPA patterns during this critical period of adolescence as a basis for improving physical activity promotion strategies and preventing the declining trajectory of MVPA into adulthood (Gordon-Larsen et al., 2004; Ortega et al., 2013; Telama, 2009).

Adolescents engage in MVPA through active transportation and recreation in multiple locations, including homes, schools, neighborhoods, and recreation areas (Grow et al., 2008). Active travel, in particular, has been related to more overall physical activity in numerous studies (Bassett et al., 2013; Cooper et al., 2005; Faulkner et al., 2009; Larouche et al., 2014). Previous studies that examined MVPA across locations in adolescence have done so by describing and comparing the amount of time spent in individual locations and by exploring how demographic and other explanatory variables are associated with MVPA in individual locations (Carlson et al., 2017; Maddison et al., 2010; Oreskovic et al., 2012; Rainham et al., 2012). These previous studies have relied on variable-centered analyses. However, variable-centered analyses do not allow for understanding of co-occurrence of

physical activity across different locations within individuals. A complementary approach is to use person-centered analyses to identify subsets of adolescents based on their patterns of MVPA across locations. This approach allows for the identification of naturally occurring profiles/groups of adolescents based on where they accumulate MVPA and allows for the exploration of differences between these profiles. In particular, knowing whether patterns of MVPA accumulation across locations are related to overall MVPA, walking to school, and other participant and environment characteristics would inform settings-based and cross-setting (e.g., transportation) interventions.

The present study was among the first to use person-centered analyses (i.e., latent profile analysis) to identify naturally occurring patterns of young adolescents' MVPA across locations using GPS and accelerometry. Study objectives were to investigate (1) whether youth clustered into profiles based on where they accumulated MVPA, and (2) whether overall MVPA, walking to school, and participant and neighborhood characteristics differed across profiles. Only schooldays were investigated because they account for most of the week and adolescents' overall MVPA (Comte et al., 2013), likely involve distinct location-patterns of physical activity as compared with weekend days, and provide more heterogeneity in physical activity locations than provided by weekend days, particularly in regard to school physical activity, neighborhood activity, and active travel to school.

2. METHODS

2.1. Participants and Procedures

The current data were drawn from the Teen Environment and Neighborhood (TEAN) study of built environments and physical activity. This study was conducted in the Baltimore, MD/Washington, DC and Seattle/King County, WA regions of the USA from 2009 to 2011. A total of 928 healthy adolescents (ages 12–16 years), and one of their parents, participated in the larger TEAN study. TEAN participants were selected from 447 census block groups and were evenly distributed across four block group types of (high or low) walkability and (high or low) income, as assessed by previously reported methods (Frank et al., 2010; Sallis et al., 2018). Recruitment was conducted via mail and telephone. Ineligibility criteria included any condition affecting their physical activity, dietary habits, or ability to participate.

A subset of participants was instructed to wear a Global Positioning System (GPS) tracker and an accelerometer for seven days during all waking hours, except during times when the devices could get wet. From the initial 928 participants, a total of 400 were determined ineligible for present analyses and were excluded due to not being given a GPS device (N = 130), not wearing an accelerometer and a GPS simultaneously for at least one valid school day (N = 148), and geocoding errors (N = 122). Thus, the final sample for the current study included 528 adolescents.

2.2. Measures

Demographics: Participating adolescents self-reported their age, gender, and ethnicity. Parent participants self-reported their highest level of education. Ethnicity was represented as whether or not the participant identified as white (non-Hispanic). Parent education was

represented as whether or not either parent/guardian had received a college degree. Using the methods for identifying neighborhoods to include in the study, the median annual household income (based on 2000 census) was deciled and then dichotomized by defining the 1st through 4th deciles as "low income" (Baltimore: $15,466 to $40,700; Seattle/King County: $25–431 to $49,012) and the 7th, 8th, and 9th deciles as "high income" (Baltimore: $62,450 to $86,932; Seattle/King County: $65,752 to $81,865). The highest decile of income was omitted to eliminate outliers with very high income and thus maximize generalizability.

Physical activity: Minutes of MVPA were assessed with ActiGraph accelerometers (Models 7164, 71256, GT1M, GT3X). Epoch length was set to 30-seconds, and MVPA was derived from the Evenson cut points for vertical axis acceleration counts (Evenson et al., 2008). Non-wear periods were considered >60 consecutive epochs (30 minutes) with count = 0, and such periods were excluded from analyses. Only school days were included in the analyses, defined as any weekday during which the participant spent ≥200 minutes of time at school based on the GPS. Minutes spent in MVPA were used for the current analyses. Participants were also categorized into meeting or not meeting the recommended 60 minutes/day of MVPA, calculated as whether or not participants' average MVPA (across days) fell above or below this cutoff.

GPS tracking: Participants were instructed to wear a GlobalSat DG-1 GPS tracker (GlobalSat, New Taipei City, Taiwan), and latitude and longitude data were collected at 30-second epochs (Rainham et al., 2012). GPS and accelerometer data were merged using the Personal Activity and Location Measurement System (Center for Wireless & Population Health Systems, 2012; Center for Wireless and Population Health Systems, La Jolla, CA). Only combined GPS and accelerometer data could be included in the analysis. A minimum of eight hours of daily accelerometer wear time was required for the day to be included (Mattocks et al., 2008), and a minimum of one valid day for the participant to be included. All accelerometer wear time must have coincided with valid GPS data to be included. Participants who never left their home over the one-week period (as determined by the GPS) were considered to have not worn the device.

Locations of physical activity were categorized into the following: "home," "home neighborhood," "school," "school neighborhood," and "other" locations. Each participant's home and school addresses were geocoded and integrated into ArcGIS (ESRI, Inc., Redlands, CA). Buffers around each address (home and school) created a radius to define each location of interest (at home: 50-m-radius circular buffer around home address geocoded point; at school: 15-m buffer around school parcel; near home: 1-km street network buffer around home address, excluding the "at-home" and "at-school" buffers; near school: 1-km street network buffer around school address, excluding the "at-home" and "at-school" buffers; and all other locations: any location not included in the previous four locations). The participant-specific location and GPS information were merged into a PostgreSQL database (PostgreSQL Global Development Group, Berkeley, CA) to analyze when and for how long participants were within any of the five locations. Number of minutes per day and number of minutes of MVPA spent in each location were then calculated. For participants whose home and school neighborhood overlapped (N = 110), the

overlapping wear time and MVPA time were divided by 2 and split evenly across the two locations.

Neighborhood walkability: A walkability index was derived in GIS for a 1km street-network buffer around each participant's home neighborhood, using measures of net residential density, road intersection density, mixed land use, and pedestrian design of retail space (i.e., the ratio of retail building square footage divided by retail land square footage; a lower ratio often reflects a higher amount of parking, which decreases likelihood of pedestrian access; Frank et al., 2010). The four variables were standardized to have a mean of 0 and standard deviation of 1 (i.e., z score), based on the neighborhoods selected for recruitment, and summed so each would contribute equal weight to the index. Walkability scores were deciled and categorized by median split procedures to represent lower or higher walkability.

Park access: Data from the county tax assessor on land use was integrated into GIS to determine the presence or absence of at least one park within a 500-meter street network buffer around the participant's home (yes/no). The smaller 500-meter buffer was used for park access because prior studies have found stronger associations with MVPA at this buffer size (Sallis et al., 2016), and a majority of adolescents had parks within 1km buffers, providing limited variability.

Neighborhood safety: Neighborhood safety was assessed via the parent-report Neighborhood Environment Walkability Scale for Youth (NEWS-Y; Rosenberg et al., 2009). Traffic safety (3 items; e.g., traffic makes it unpleasant to walk), pedestrian safety (3 items; e.g., crosswalks on busy streets), and crime safety (5 items; e.g., high crime rate) items were averaged into individual subscale scores for analyses. Previous investigations have demonstrated adequate test-retest reliability (ICCs = 0.61–0.78; Rosenberg et al., 2009).

Parent physical activity rules: Parents reported on 18 possible rules (yes/no) they enforced regarding their child's participation in physical activity and sedentary activity (Tandon et al., 2012), and the 11 items expected to restrict adolescent physical activity were summed for present analyses[1] (e.g., do not go places alone, do not cross busy streets, do homework before going out, stay in the neighborhood).

Distance to school: GIS data were used to calculate the shortest street-network distance from home to school in meters.

Regular walking to school: An adaptation of a measure from the Centers for Disease Control and Prevention's Kids-Walk-to-School program (Carlson, Sallis, et al., 2014) was used, which asked adolescents to report both the number of days they travelled to, and from, school by walking in a typical school week. Previous investigations have determined adequate test-retest reliability of this measure (Joe et al., 2012; Timperio et al., 2006). Participants were dichotomized into regular walking (5–10 trips per week) or not (<5 trips

[1]The full 18-item Parent Physical Activity Rules measure is included as on online supplement to this manuscript.

per week) to capture a level of regular walking that is achievable for youth in the US, and contributes meaningfully to overall physical activity.

Involvement in team sports/structured activities: Participants self-reported the number of sports teams or after school physical activity classes they participated in over the past year. Individual items assessed participation at school and outside of school. Item responses were transformed from count to any sports participation (i.e., yes/no) for current analyses.

Athletic ability: Participants self-reported their perceived athletic ability ("How do you rate your athletic ability compared to your peers?") on a scale of 1–5 (much lower (1), somewhat lower (2), same level (3), somewhat higher (4), much higher (5)).

2.3. Data Analyses

Latent profile analysis (LPA) was conducted with five participant-level indicator variables representing MVPA minutes/day in each of five locations (i.e., home, home neighborhood, school, school neighborhood, and other locations). Models were compared to derive the number of profiles that best fit the data, taking into consideration the Lo–Mendell–Rubin test (LMR), McLachlan's bootstrapped likelihood ratio test (BLRT) test, change in Bayesian Information Criterion (BIC), entropy values, group sample sizes, and interpretability of the profiles. Due to the large proportion of participants in one profile from the latent profile analysis, a second latent profile analysis was conducted on the participants in this large profile. Differences in demographic, MVPA (total and in each location), and other key variables were explored across the emerging profiles by conducting mixed effects linear regression analyses with dummy variables to compare each profile. These models were estimated in Mplus version 6, with block group identifier entered as a cluster variable to account for the nested design and using the MLR estimator which is robust to non-normal distributions. Between-group differences with a p value < 0.01 were considered significant.

3. RESULTS

3.1 Demographics

Participants had a mean age of 14.12 (SD = 1.44), 50% were girls, 69% were White non-Hispanic, 46% lived in a high-walkability neighborhoods, 50% in high-income neighborhoods, and 52% resided in the Seattle/King County, WA region. Participants wore the acceleromter and GPS devices for a mean of 3.9 (SD = 1.5) school days.

3.2 Latent Profile Analysis

The BLRT ($p < 0.001$) and reduction in BIC supported a 4-profile over 3-profile solution. Although the model fit estimates indicated a 5-profile solution was also possible, the improvement in BIC was very small (0.67%). Thus, the 4-profile solution was retained and an additional LPA was conducted on the largest profile, which captured 90% of participants. Similar to the first LPA, the model fit indices supported a 4- vs. 3-profile solution. BLRT ($p < 0.001$), but not LMR ($p = 0.380$), supported a 5- vs. 4-profile solution. The 4-profile solution was chosen because it produced reasonable sample sizes per class and interpretable

profiles. Entropy for the first LPA (4-profile solution) was 0.99, and 0.94 for the second LPA (4-profile solution), indicating a clear delineation of classes (values closest to 1 are optimal).

3.2.1 First Latent Profile Analysis—The first latent profile analysis produced four profiles of activity locations (Figure 1). Adolescents in all four profiles had similar amounts of MVPA during the school day, ranging from 20.0 to 30.3 minutes/day, and in the home (4.9 – 5.7 minutes/day). Adolescents in the Insufficiently Active profile (N = 475, 90%) generally had low amounts of MVPA in each of the five locations. The remaining three profiles were considered the "Active" profiles and each was distinguished by higher amounts of MVPA in one location ("Active Around School", N = 17, 3%; "Active Home Neighborhood", N = 14, 3%; and "Active Other Locations", N = 22, 4%) as compared with the other profiles. Adolescents in the three Active profiles had substantially higher amounts of overall MPVA (70.2 – 92.7 minutes/day for the three Active profiles vs. 38.3 minutes/day for Insufficiently Active profile) and were substantially more likely to meet the 60-minutes/day MVPA guideline (59% – 86% for Active profiles vs. 12% for Insufficiently Active profile; Table 1) than adolescents in the Insufficiently Active profile.

Demographics, neighborhood characteristics, school travel, and rates of sports/activity class participation differed among profiles. Participants in Active Home Neighborhood were less likely to be female (21%) compared with participants in Insufficiently Active; (52%). Active Around School was distinguished by higher levels of regular walking to school (47%) when compared with Insufficiently Active (18%) and Active Home Neighborhood (7%). Although only significant at $p < 0.05$, Active Around School also demonstrated higher levels of neighborhood walkability (77% for Active Around School vs. 44% – 57% for Insufficiently Active, Active Home Neighborhood, and Active Other Locations). When compared with Insufficiently Active, adolescents in Active Other Locations self-reported higher levels of outside-school sport participation (91% for Active Other Locations vs. 68% for Insufficiently Active) and athletic ability (3.9 [out of 5] for Active Other locations vs. 3.4 for Insufficiently Active; Table 1).

3.2.2 Second Latent Profile Analysis—A second LPA was conducted on the participants from the Insufficiently Active profile of the original LPA. Four additional profiles emerged (Figure 2). In terms of MVPA locations, two profiles were similar to Active Around School and Active Home Neighborhood from the first latent profile analysis, and were therefore distinguished with the "moderate" characterization in each title. Adolescents in the second Insufficiently Active profile (N = 353, 74%) had low amounts of MVPA (<5 minutes in 4 of the 5 locations) across the locations. The remaining three Active profiles were characterized by higher amounts of MPVA in one location ("Moderately-Active Around School", N = 39, 8%; "Moderately-Active Home Neighborhood," N = 48, 10%; and "Active At Home", N = 35, 7%). Adolescents in the three Active profiles had higher amounts of overall MVPA (41.1 – 62.6 minutes/day for Active Profiles vs. 34.5 minutes/day for Insufficiently Active). Only adolescents in Active At Home were more likely to meet the 60-minutes/day MVPA guideline (48.6% for Active At Home vs. 7% – 23% for Insufficiently Active, Moderately-Active Around School, and Moderately-Active Home Neighborhood; Table 2).

Participant and environmental variables were also associated with membership in each of the four profiles from the second LPA. Adolescents in Active At Home were less likely to be female than adolescents in Insufficiently Active (34% vs. 57%), and adolescents in Moderately-Active Around School were more likely than adolescents in Insufficiently Active to have parents with a college degree (82% vs. 62%). Adolescents in Moderately-Active Around School had the highest levels of MVPA in the school neighborhood (8.3 minutes/day) and also showed higher levels of walking to school (44.4% for Moderately-Active Around School vs. 15% for both Insufficiently Active and Moderately-Active Home Neighborhood), as well as a trend toward significance for higher levels of walkability (54% for Moderately-Active Around School vs. 40% – 44% for Profiles Insufficiently Active, Moderately-Active Home Neighborhood, and Active At Home). Adolescents in Active At Home were characterized by being active at home (22.9 minutes/day).

4. DISCUSSION

Present findings showed that young adolescents can be grouped into multiple clusters/profiles based on where they accumulated physical activity on school days across five frequently encountered locations. Each four-profile model fit the data better than a model with fewer profiles. However, the great majority of adolescents were grouped into the Insufficiently Active profile/s, and few were grouped into one of the Active profiles. Overall MVPA was substantially higher in the six Active profiles as compared with the two Insufficiently Active profiles, showing there were multiple ways and locations in which adolescents were able to achieve sufficient amounts of MVPA.

This study was among the first to show that location-based patterns of physical activity relate to overall MVPA and active transportation. Each profile of more-active adolescents was characterized by particularly high amounts of MVPA in one location type. Adolescents in profiles with high amounts of MVPA in the home and school neighborhoods, other locations, and to a lesser extent the home location, were about five-eight times more likely to meet the 60-minute/day MVPA guideline (US Department of Health and Human Services, 2008) than those in the Insufficiently Active profiles. These findings suggest that interventions promoting activity in home neighborhoods, school neighborhoods, and other locations are most promising for increasing overall physical activity, but there should be increased focus on finding the right match between the individual and physical activity source/location. For example, supporting active travel and school neighborhood activity may be most beneficial for those who are able to walk to/from school. Additionally, supporting sports participation in "other locations" may be most beneficial for those who enjoy and have perceived competence for athletics.

The profile with the highest (86%) rates of meeting the 60-minute/day physical activity guideline was the Active Home Neighborhood profile. Neighborhood walkability and sports participation were somewhat, but not significantly, higher in this profile than the Insufficiently Active profile, so these factors may explain some, but not all, of the substantial amount of MVPA (mean = 50.3 minutes/day) these participants obtained in the home neighborhood. It is likely this profile is largely explained by neighborhood play, which has been shown to be an important contributor to overall MVPA in other studies (Grow et al.,

2008; Veitch et al., 2006). A similar profile emerged, Moderately-Active Home Neighborhood, but with lower overall MVPA, further supporting the importance of neighborhood-based activity for increasing overall MVPA in adolescents. Although walkability was not significantly more favorable in these profiles, other aspects of the neighborhood environment related to "playability" may be important and thus should be investigated in future research, such as cul-de-sacs, meadows, treed areas, yards at home, low speed roads, recreational facilities, and traffic calming features (Janssen & Rosu, 2015).

Those in the Active Other Locations profile had the second highest (82%) rates of meeting the 60-minute/day physical activity guideline. This profile was characterized by high rates of sports participation both at school and outside of school, and the highest self-reported athletic ability. Most (41%, 38.1 minutes/day) of participants' overall MVPA in this profile occurred in other locations, potentially sports and recreation facilities. Previous studies using self-report showed that primary "other" locations for physical activity in adolescents included parks, open spaces, and sports fields/courts (Grow et al., 2008). Present findings indicated that for some adolescents, sports participation may lead to large amounts of total physical activity. Unfortunately, the number of adolescents in this profile was small (N = 22; 4%), which speaks to the fact that although a large number of youth participate in sports (Leek et al., 2011), the amount of physical activity accrued during sports is often lower than expected (National Council of Youth Sports, 2008). Further, barriers such as drop out, gender bias, cost, and exclusiveness can inhibit sports particiption, particularly for the adolescent age group (Kanters et al., 2008; Kanters et al., 2013; Sirard et al., 2006). On the other hand, higher levels of sport availability, higher quality of sport management, and greater availability of sport grounds at school (Mandic et al., 2012) were associated with greater sports participation. Other internal characteristics, including self-efficacy for physical activity, have been associated with higher participation in sports, and improving confidence to be active should be a focus of attention, particularly among girls (Barr-Anderson et al., 2007).

The profile with the third highest (59%) rates of meeting the 60-minute/day physical activity guideline was the Active Around School profile. This profile was largely explained by active travel to and from school, which was higher in this profile than the other profiles. This finding is in agreement with previous studies showing that youth who engage in active travel obtain more overall MVPA than their counterparts (Bassett et al., 2013; Cooper et al., 2005; Faulkner et al., 2009; Larouche et al., 2014). Walkability was also higher in this profile, but the differences were not significant at the $p < 0.01$ level. Participants in this profile obtained a high amount of phyical activty in the school neighborhood, but this group also tended to be more activity in the home neighborhood and other locations than those in the other profiles. The Moderately-Active Around school profile was very similar to the Active Around School profile, except the amounts of physical activity in each location and overall were somewhat lower. Active travel to school has been associated with higher amounts of overall MVPA in multiple studies (Faulkner et al., 2009). Although the number of adolescents in this profile was small (N = 17; 3%), supporting active travel to school by improving neighborhood built environments and adopting Safe Routes to School programs (McDonald et al., 2014; Stewart et al., 2014) may expand opportunities for daily activity through active transport.

The fourth highest (49%) rates of meeting the 60-minute/day physical activity guideline were observed for the Active At Home profile. This profile was not explained by neighborhood characteristics, but it did have slightly higher levels of sports participation and athletic ability than most other profiles. Adolescents in this profile likely engaged in larger amounts of active play inside and directly outside of the home than those in other profiles. Home and neighborhood play are particularly important sources of physical activity for children, but home-based recreational play activities (e.g, playground activities, informal sports, backyard games) typically decline during adolescence (Holt et al, 2008). Thus, encouraging adolescents to engage in more physically demanding activites at home (e.g., active video games, family-based active games, home exercise equipment, driveway basketball) in place of sedentary activities may support continued activity at home.

The purpose of conducting the second latent profile analysis was to determine whether additional profiles would emerge from the large (N = 475) Insufficiently Active profile from the first analysis. Two of the emerging profiles, (Moderately-Active Around School and Moderately-Active Home Neighborhood), were similar to profiles from the first analysis, but with lower amounts of physical activity, and similar participant and environment characteristics explained these profiles. Thus, the validity of these profiles was supported through replication, providing additional rationale for the importance of school neighborhood and home neighborhood-based activity to increasing overall physical activity in youth. Findings suggested that most adolescents did not engage in large amounts of school or home neighborhood phyical activity, but a larger proportion of school and home neighbrhood time was spent physically active as compared with most other locations. Youth who engage in school or home neighborhood activity typically have substantially more overall activity than their counterparts (Carlson et al., 2016; Kneeshaw-Price et al., 2013).

Although differences in school-based MVPA across profiles were smaller than differences in MVPA for each of the other locations, the difference was still meaningful (up to about 10 minutes/day). It should be noted that school MVPA was not a primary explanatory variable of profile membership. Previous literature showed the importance of school-based physical activity to overall MVPA and health (Pate et al., 2006), and it is clear that student physical activity can vary drastically across schools (Carlson, Mignano, et al., 2014; Carlson et al., 2013) Supporting more physical activity in the school setting may also help more youth achieve guidelines for physical activity. Such initiatives may include Coordinated School Physical Activity Programs (CSPAP), increased time in physical education, opportunities for activity during lunch-time, and integration of physical activity into classroom lessons (Carson et al., 2014; Centers for Disease Control and Prevention, 2013; Hills et al., 2015). However, an implication of the present study is that there is likely an upper limit with regards to how much MVPA schools can provide, and outside opportunities such as active travel, active play, and sports/active recreation appear to be critical for supporting youth to meet physical activity guidelines.

4.1. Strengths and Limitations

Study strengths included use of accelerometers and GPS to obectively assess physical activity in different locations. The purposeful inclusion of both high and low walkable home

neighborhoods improved our ability to assess the role of neighborhood factors. Among the limitations, only weekdays were investigated, so findings can not be generalized to weekend days or summers. Weekend activities may change the number of participants meeting guidelines (Comte et al., 2013) and may change the importance of certain locations (e.g., no/limited physical activity at school on weekends; Carlson et al., 2017). Location-patterns of physical activity should be investigated on weekend days, and more specific examination of locations within the "other" category would likely be needed. Based on how the locations were classified, there is little understanding of where adolescents were active when they were in "other" locations. In addition, GPS signals can be unreliable when indoors. Specifically, misclassification may have occurred, such as discriminating in-home from home neighborhood and in-school from school neighborhood, although the PALMS system allowed "smoothing" to reduce such interference. Additional limitations included small sample size in some profiles, which limited power to detect meaningful differences between profiles (e.g., neighborhood walkability). Also, the TEAN study design was limited to adolescents living in urban/suburban neighborhoods with either higher or lower walkability and, therefore, may not represent the all types of neighborhoods in which adolescents live. Finally, the current study was observational, which limits the ability to determine causality.

4.2. Implications for policy and practice

The emerging profiles, each characterized by a different primary location of physical activity, demonstrated there are multiple ways to support increases in overall physical activity in adolescents. It was clear that adolescents characteristically were active in a limited number of locations during the week. Although the highly active profiles included only a small number of participants, even moving from the insufficiently active profile to one of the "moderate activity" profiles could lead to meaningful increases in overall physical activity.

Increasing neighborhood recreational activity and active travel appear to be particularly promising approaches for impacting population health. Multiple strategies for increasing overall physical activity are likely needed, including adoption of complete streets policies (Smart Growth America), which require designing streets to meet the needs of all users, including pedestrians, bicyclists, public transport users, and people with disabilities (e.g., buffer between sidewalks and street, protected bicycle facilities, curb ramps, and traffic calming), and Safe Routes to School programs (McDonald et al., 2014; Stewart et al., 2014), which support youth to walk to/from school. In particular, finding the right match between the individual and physical activity source/location should be considered, such as investing in active travel to school promotion for students from schools in walkable neighborhoods, promoting home and home-neighborhood activity among youth who spend large amounts of time at home, and increasing access to sports and recreation facilities to accommodate adolescents interested in sports. However, home neighborhood-related policies such as complete streets, mixed use development, and park enhancements are challenging because local leaders can be lacking and progress may be slow. Lower-cost strategies such as 'playstreets' may be effective in dedicating more neighborhood space to play (D'Haese et al., 2015).

4.3. Conclusions

On school days, adolescents accrued physical activity in multiple locations. The large majority of adolescents did not accrue sufficient physical activity to achieve guidelines. However, adolescents who had a profile of physical activity that involved high levels of activity to and around school, in the home neighborhood, in “other” locations, or to a lesser extent at home, were most likely to meet physical activity guidelines. Active travel to school, home neighborhood activity/play, and sports participation appeared to be key characteristics that explained the active profiles. Health promotion efforts targeting the aforementioned locations and characteristics have strong potential to improve overall physical activity in youth. Tailored strategies may be needed to find the best match between the individual and source/location of physical activity, because there appear to be multiple locations that can lead to sufficient overall physical activity. A next step would be to use findings from the present study to create interventions tailored to location characteristics and adolescent preferences to improve physical activity outcomes.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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HIGHLIGHTS

- Patterns of physical activity across locations were related to overall activity.
- Main locations for physical activity varied across adolescent clusters.
- Neighborhood activity and active travel were key distinguishers of active adolescents.
- Identifying the best location-person match could support targeted interventions.

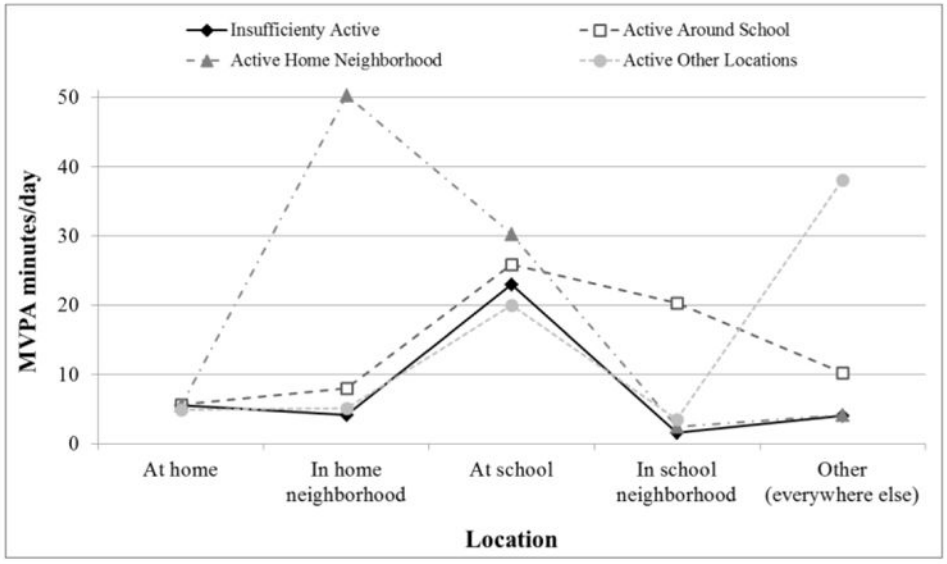

Figure 1.

Four latent profiles of patterns of phsyical activity by location from the first latent profile analysis (N = 528 adolescents)

Note: MVPA = moderate to vigorous physical activity

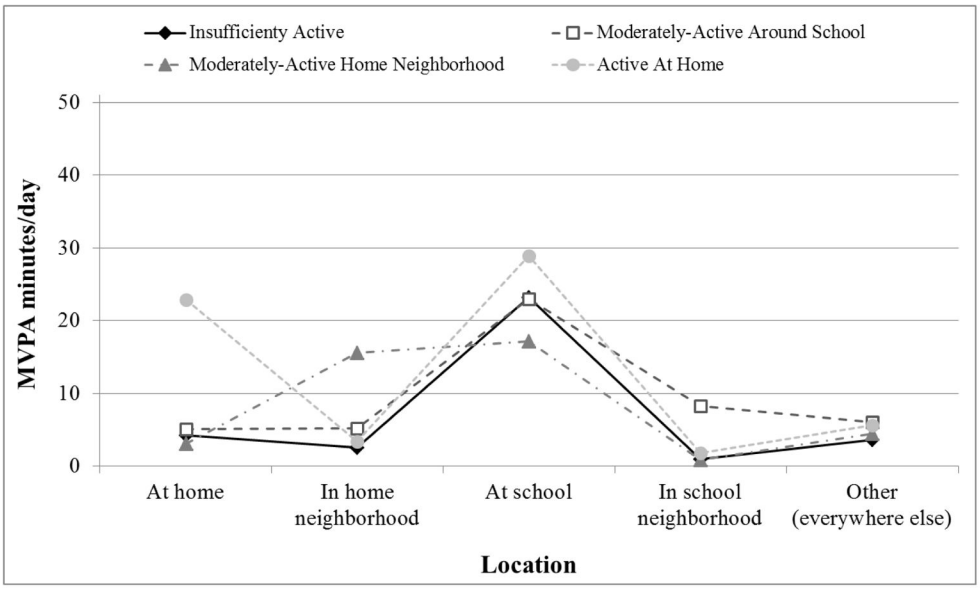

Figure 2.

Four latent profiles of patterns of phsyical activity by location from the second latent profile analysis (N = 475 adoloscents from Profile 1 in the first latent profile analysis)

Note: MVPA = moderate to vigorous physical activity

Table 1

Differences in physical activity, demographics, and other physical activity-related factors across profiles in the first latent profile analysis (N = 528 adolescents)

	Insufficiently Active N = 475 (90%)		Active Around School N = 17 (3%)		Active Home Neighborhood N = 14 (3%)		Active Other Locations N = 22 (4%)	
	Mean or % (SE)	Significant differences[a]	Mean or % (SE)	Significant differences[a]	Mean or % (SE)	Significant differences[a]	Mean or % (SE)	Significant differences[a]
Physical activity by location								
Home MVPA (min/day)	5.5	none	5.7	none	5.5	none	4.9	none
	(0.3)		(1.0)		(3.6)		(1.0)	
Home neighborhood MVPA (min/day)	4.1	3	8.0	3	50.3	1, 2, 4	5.1	3
	(0.2)		(2.1)		(3.7)		(1.0)	
School MVPA (min/day)	23.0	none	25.9	none	30.3	none	20.0	none
	(0.7)		(3.4)		(3.6)		(1.7)	
School neighborhood MVPA (min/day)	1.6	2	20.3	1, 3, 4	2.4	2	3.5	2
	(0.1)		(1.2)		(0.9)		(0.9)	
Other location MVPA (min/day)	4.0	4	10.3	4	4.2	4	38.1	1, 2, 3
	(0.2)		(3.1)		(1.7)		(2.7)	
Overall physical activity								
Meeting 60 min/day guideline (yes)	12%	2, 3, 4	59%	1	86%	1	82%	1
	(1.5)		(12.0)		(8.8)		(8.3)	
Overall MVPA (min/day)	38.3	2, 3, 4	70.2	1	92.7	1	71.7	1
	(0.9)		(6.2)		(5.8)		(2.9)	
Demographics								
Age (years)	14.2	none	14.2	none	13.4	none	13.8	none
	(0.1)		(0.4)		(0.4)		(0.3)	
Female (yes)	52%	3	41%	none	21%	1	41%	none
	(2.4)		(12.0)		(9.3)		(10.6)	
White non-Hispanic (yes)	71%	none	53%	none	57%	none	64%	none
	(2.3)		(12.1)		(13.0)		(10.4)	
Parent with college degree (yes)	64%	none	82%	none	50%	none	59%	none

	Insufficiently Active N = 475 (90%)		Active Around School N = 17 (3%)		Active Home Neighborhood N = 14 (3%)		Active Other Locations N = 22 (4%)	
	Mean or % (SE)	Significant differences[a]	Mean or % (SE)	Significant differences[a]	Mean or % (SE)	Significant differences[a]	Mean or % (SE)	Significant differences[a]
	(2.4)		(9.3)		(13.4)		(10.6)	
High income (yes)	50%	none	41%	none	57%	none	55%	none
	(3.6)		(12.0)		(12.1)		(10.8)	
Environment								
High walkability (yes)	44%	none	77%	none	57%	none	55%	none
	(3.6)		(10.3)		(14.6)		(10.8)	
Park access (yes)	35%	none	41%	none	50%	none	41%	none
	(2.8)		(12.0)		(15.2)		(10.6)	
Traffic safety [1–4]	2.6	none	2.6	none	2.6	none	2.6	none
	(0)		(0.2)		(0.2)		(0.1)	
Pedestrian safety [1–4]	2.8	none	2.8	none	2.9	none	2.8	none
	(0)		(0.2)		(0.1)		(0.1)	
Crime safety [1–4]	3.0	none	3.1	none	3.2	none	3.0	none
	(0)		(0.2)		(0.3)		(0.2)	
Parent Rules [0–11]	4.1	none	3.8	none	4.2	none	3.8	none
	(0.1)		(0.6)		(0.6)		(0.4)	
Travel to school								
Distance to school (km)	5.4	none	5.5	none	5.1	none	7.4	none
	(0.3)		(1.7)		(0.8)		(1.4)	
Regular walking to school (yes)	18%	2	47%	1, 3	7%	2	23%	none
	(1.8)		(12.1)		(6.4)		(9.1)	
Sports								
Any school sports (yes)	69%	none	77%	none	79%	none	86%	none
	(2.1)		(10.3)		(12.9)		(7.4)	
Any sports outside school (yes)	68%	4	88%	none	79%	none	91%	1
	(2.2)		(7.8)		(13.7)		(6.2)	
Athletic ability [1–5]	3.4	4	3.8	none	3.7	none	3.9	1
	(0)		(0.2)		(0.4)		(0.2)	

Note:

[a] $p < 0.01$

Table 2

Differences in physical activity, demographics, and other physical activity-related factors across profiles in the second latent profile analysis (N = 475 adolescents from Profile 1 in the first latent profile analysis)

	Insufficiently Active N = 353 (75%)		Moderately-Active Around School N = 39 (8%)		Moderately-Active Home Neighborhood N = 48 (10%)		Active At Home N = 35 (7%)	
	Mean or % (SE)	Significant differences[a]	Mean or % (SE)	Significant differences[a]	Mean or % (SE)	Significant differences[a]	Mean or % (SE)	Significant differences[a]
Physical activity by location								
Home MVPA (min/day)	4.2	4	5.1	4	3.1	4	22.9	1, 2, 3
	(0.2)		(0.7)		(0.7)		(1.2)	
Home neighborhood MVPA (min/day)	2.5	2 ,3	5.2	1, 3	15.6	1 ,2, 4	3.4	3
	(0.1)		(0.6)		(0.6)		(0.5)	
School MVPA (min/day)	23.2	3	23.0	none	17.2	1, 4	28.9	3
	(0.8)		(2.1)		(1.7)		(2.6)	
School neighborhood MVPA (min/day)	1.0	2	8.3	1, 3, 4	0.9	2	1.8	2
	(0.1)		(0.3)		(0.2)		(0.3)	
Other location MVPA (min/day)	3.6	none	6.0	none	4.4	none	5.6	none
	(0.2)		(0.9)		(0.7)		(1.1)	
Overall physical activity								
Meeting 60 min/day guideline (yes)	7.1%	4	23.1%	none	8.3%	4	48.6%	1, 3
	(1.4)		(6.8)		(4.1)		(8.0)	
Overall MVPA (min/day)	34.5	2, 3, 4	47.5	1, 4	41.1	1, 4	62.6	1, 2, 3
	(0.9)		(2.9)		(2.0)		(3.3)	
Demographics								
Age (years)	14.2	none	14.2	none	14.3	none	13.6	none
	(0.1)		(0.2)		(0.2)		(0.2)	
Female (yes)	57%	4	44%	none	40%	none	34%	1
	(2.8)		(8.0)		(7.1)		(7.5)	
White non-Hispanic (yes)	71%	none	74%	none	65%	none	77%	none
	(2.6)		(7.2)		(7.5)		(6.6)	

	Insufficiently Active N = 353 (75%)		Moderately-Active Around School N = 39 (8%)		Moderately-Active Home Neighborhood N = 48 (10%)		Active At Home N = 35 (7%)	
	Mean or % (SE)	Significant differences[a]	Mean or % (SE)	Significant differences[a]	Mean or % (SE)	Significant differences[a]	Mean or % (SE)	Significant differences[a]
Parent with college degree (yes)	62% (2.8)	2	82% (6.2)	1	58% (7.7)	none	74% (7.7)	none
High income (yes)	50% (3.9)	none	46% (8.0)	none	58% (8.2)	none	49% (9.5)	none
Environment								
High walkability (yes)	44% (3.8)	none	54% (8.0)	none	42% (8.7)	none	40% (9.3)	none
Park access (yes)	35% (2.9)	none	33% (7.6)	none	40% (8.8)	none	34% (9.1)	none
Traffic safety [1–4]	2.6 (0.0)	none	2.6 (0.1)	none	2.6 (0.1)	none	2.7 (0.1)	none
Pedestrian safety [1–4]	2.8 (0.0)	none	2.8 (0.1)	none	2.7 (0.1)	none	2.9 (0.1)	none
Crime safety [1–4]	3.0 (0.0)	none	2.9 (0.1)	none	3.1 (0.1)	none	3.1 (0.1)	none
Parent Rules [0–11]	4.3 (0.1)	none	3.6 (0.4)	none	4.0 (0.3)	none	3.7 (0.4)	none
Travel to school								
Distance to school (km)	5.7 (0.3)	none	4.4 (0.8)	none	4.8 (0.4)	none	4.2 (0.7)	none
Regular walking to school (yes)	15% (0.0)	2	44% (8.3)	1, 3	15% (4.7)	2	24% (7.3)	none
Sports								
Any school sports (yes)	70% (2.4)	none	72% (7.5)	none	58% (7.3)	none	77% (7.9)	none
Any sports outside school (yes)	67% (2.6)	none	77% (6.8)	none	60% (7.2)	none	80% (7.7)	none
Athletic ability [1–5]	3.4	none	3.5	none	3.4	none	3.6	none

	Insufficiently Active N = 353 (75%)		Moderately-Active Around School N = 39 (8%)		Moderately-Active Home Neighborhood N = 48 (10%)		Active At Home N = 35 (7%)	
	Mean or % (SE)	Significant differences[a]	Mean or % (SE)	Significant differences[a]	Mean or % (SE)	Significant differences[a]	Mean or % (SE)	Significant differences[a]
	(0.1)		(0.1)		(0.2)		(0.2)	

Note:

[a] $p < 0.01$