Title: It's a-bout time: Detailed patterns of physical activity in obese adolescents participating in a lifestyle intervention

Running Title: Detailed activity patterns in obese adolescents

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Abstract

Background: The detailed patterns of physical activity and sedentary behaviors of overweight and obese adolescents are unknown, but may be important for health outcomes and targeted intervention design.

Methods: Participants completed Curtin University's Activity, Food and Attitudes Program (CAFAP), an 8-week intervention with 12 months of maintenance intervention. Physical activity and sedentary time were assessed at 6 time periods with accelerometers and were analysed by 1) time and type of day 2) intensity bout patterns using exposure variation analysis, and 3) individual case analysis.

Results: Participants (n=~~69~~56) spent a lower percentage of time at baseline in light activity during school days compared to weekend days (24.4% vs 29.0%, p=.004). The majority of time was in long uninterrupted sedentary bouts of greater than 30 minutes (26.7% of total time, 36.8% of sedentary time at baseline). Moderate activity was accumulated in short bouts of less than 5 minutes (3.1% of total time, 76.0% moderate time). Changes varied by individuals.

Conclusions: Exposure variation analysis revealed specific changes in activity patterns in overweight and obese adolescents who participated in a lifestyle intervention. A better understanding of these patterns can help to design interventions that meaningfully affect specific behaviors, with unique health consequences.

Introduction

A high proportion of children and adolescents are physically inactive and sedentary, especially adolescents who are overweight or obese.[1] These low levels of physical activity and high levels of sedentary behavior have negative and independent health implications beyond obesity, including poor metabolic profiles and increased risk for cardiovascular disease and other morbidities in adulthood.[2] Physical activity and sedentariness are independent, and active adolescents (achieving recommended 60 minutes of activity) can also be highly sedentary.[3] Thus, interventions are needed to improve both physical activity and sedentary behavior, and adolescence has been identified as a critical period to intervene.[4] One such intervention was Curtin University's Activity, Food, and Attitudes Program (CAFAP), which was a community-based, family-centred lifestyle intervention focused on increasing physical activity and decreasing sedentary behavior and eating behaviors of overweight and obese adolescents.[5]

Traditionally, physical activity intervention results have been reported as an overall change in physical activity (total, light, moderate-to-vigorous, and sedentary time) in response to an intervention. In a waitlist controlled clinical trial, participants in CAFAP had limited positive changes in objectively measured physical activity and sedentary behavior.[6] However, these overall changes in physical activity and sedentary behavior may overlook specific changes in activity patterns of overweight and obese adolescents. Detailed information about patterns in these behaviors may be useful for multiple purposes. Firstly, a better understanding of patterns of activity may be valuable information for designing successful interventions that target certain activity behaviors or times or days.[7,8] Secondly, detailed information can be used to assess adherence to key intervention messages, such as reducing prolonged bouts of sedentary time. Thirdly, recent literature has suggested that the absolute levels of activity may not be enough to explain differences in health outcomes, but particular patterns in behavior may be critical (including intensity and bout length).[9,10]

For the above reasons, researchers have begun to extract more specific details about the patterns of activity among adolescents. Adolescents accumulate less physical activity on weekends,[11] more and longer sedentary bouts on school days,[8] and a study using GPS data found different patterns and locations of physical activity on schooldays versus weekends.[12] However, there is little known about the patterns of activity of overweight and obese adolescents. A few previous studies have examined the differences in weekend versus school day behavior of obese and overweight children and adolescents.[7,13,14] Laguna et al. found no differences in physical activity between weekdays and weekends for overweight or normal weight adolescents.[7] Conversely, Treuth et al. found that both overweight and normal weight girls participated in less moderate-to-vigorous-physical-activity (MVPA) on the weekends compared to weekdays.[13] Similarly, Vanhelst et al found that participants were less active on weekends and saw greater improvements in physical activity during the weekend following a one-year intervention.[14] Laguna et al. also analysed physical activity by the hour of the day on weekdays and weekends and found no significant differences for overweight adolescents while normal weight adolescents participated in more physical activity during the afternoon and weekend compared to the morning.[7]

In addition to daily patterns of physical activity, specific patterns of physical activity intensities and durations may have differential health effects. Emerging evidence suggests that long, uninterrupted bouts of sedentary time may have uniquely detrimental health effects. Breaks in sedentary time and short bouts of higher intensity physical activity may have positive health benefits in adults and children,[15-20] though the evidence has been controversial in children.[21] One way to examine these bouts of physical activity is through exposure variation analysis (EVA). EVA provides a unique analytical approach to assess the complex patterns of physical activity and sedentary behavior,[22] and has been used to explore activity patterns during school in children.[23] Exposure variation analysis has not yet been used to examine the patterns of physical activity in overweight and obese adolescents or how these patterns may change during participation in an intervention.

The aim of this study was to examine in detail the patterns of activity among overweight and obese adolescents participating in a lifestyle intervention. A thorough description of accelerometry measured physical activity and sedentary behaviors was examined using two approaches: an increasingly common approach of breaking down weekend, school days, and the afterschool period; and a novel method of applying EVA to examine different duration and intensity bouts. These detailed patterns were examined at baseline, how these patterns changed in response to an 8-week intervention, and how the patterns persisted for one year after the intervention.

Methods and Procedures

Intervention. This study provides a detailed analysis of physical activity and sedentary time as part of a larger waitlist controlled clinical trial with details previously published.[5,6] Participants completed an 8-week intervention with 12 months of follow-up maintenance intervention. Six assessments were completed: baseline, 3 months following baseline and immediately prior to beginning the intervention (waitlist period for within subject comparison), immediately completing the 8-week intervention (intervention period), and at 3 months, 6 months, and 12 months following the intensive intervention (maintenance periods).

Participants needed to be 12 to 16 years of age, have a BMI-for-age and sex greater than the 85th percentile on the Centers for Disease Control BMI-for-age growth charts,[24] and be able to attend intervention meetings twice per week. They were excluded if they failed a medical screening or if their obesity was related to a diagnosed metabolic, genetic or endocrine disorder. A total of 69 participants (age range 11.3-16.9 years; n=55 with BMI percentile >95) enrolled in the study and a detailed participant flow diagram has been previously published.[6]

CAFAP was developed based on Self-Determination Theory and Goal Setting Theory through formative assessment with stakeholders.[25,26] The program was delivered in the community by a multidisciplinary team of a dietitian, physiotherapist/exercise scientist, and psychologist. Participants and parents attended sessions twice per week for eight weeks. The primary targets were increasing physical activity, reducing sedentary behavior and improving healthy eating. Each session included a behavior change lesson (both separately and with parents and adolescents together) and an exercise component for adolescents.[6] Exercises were designed to be fun and included team games, circuits, and other activities that they could continue after CAFAP. Behavioral sessions focused on goal setting, overcoming barriers and finding community resources.[6] Parents were guided to provide need-supportive environments for their child to make behavior changes. Following the initial 8-week intervention, participants received maintenance phone calls and text messages at a decreasing frequency for 12 months following the intervention.[27]

Activity Measures

Physical activity was measured using Actical monitors (Respironics; Bend, Oregon, USA). Participants were instructed to wear the monitors for 7 consecutive days on their right hip for all waking hours, except during water activities. Participants completed a simple activity diary to record sleep and weartime. Data were collected in 15-second epochs.

A customised LabView V7® (National Instruments, Austin, TX, USA) program was used to process the accelerometry data. Individual weartime was established through participant logs and verified with visual inspection of the data as adolescent logs may be unreliable. Periods of consecutive zeros greater than 120 minutes were considered non-weartime as research with children has used similar periods[28,29] and previous pilot work by the current research group has found valid sedentary bouts of >90 minutes in this age group. Time periods where the participant was at a study-related intervention or assessment session were removed. Previously established cut-points for children and adolescents were used to determine the minutes of sedentary (< 100 counts per minute (cpm), light (100-<1600cpm), moderate (1600-<4760), and vigorous (≥4760 cpm) physical activity per day.[30] To be included in the total day analysis, participants needed to have 3 days of valid accelerometry data and a minimum of 8 hours per whole day.[31]

Patterns by Time and Type of Day. To understand the daily patterns of physical activity, data were examined by weekend days, school days, and the afterschool period (from 3:30 PM to 6:00 PM on schooldays only). Participants needed to have one weekend day, at least two school days, or at least 2 afternoons to be included in each respective analysis. School holidays or sick days were excluded.

Breaks and Bouts Patterns. To examine interruptions in sedentary time and long uninterrupted durations of sedentary time, both considered to have detrimental health effects, sedentary breaks and bouts were calculated. Breaks in sedentary behavior were defined as sequences with counts per minute greater than 100 between bouts of sedentary time and were calculated as mean breaks per hour of sedentary time. Exposure variation analysis (EVA) was used to describe the amount of uninterrupted time spent in varying durations of activity across all intensity levels. EVA has previously been used to describe patterns of physical activity as it can capture both the intensity and continuous durations.[9,22] The EVA used 4 intensity categories (sedentary, light, moderate and vigorous physical activity) and 5 duration categories (<5 minutes, 5-<10 minutes, 10-<30 minutes, 30-<60 minutes and 60 minutes or more). The cumulative amount of time spent in each bout was calculated per day and was averaged per day of wear for a total of 20 (4 x 5) cells. As the minutes were averaged across multiple days of wear, it was possible to have an average time that was less than the minimum bout duration. The bout durations were selected to reflect brief bursts of activity, potentially health promoting bouts of at least 10 minutes [32,33] and potentially deleterious long bouts of 30+ minutes of sedentary behavior.[18]

Analysis

To provide a more detailed description of the patterns of physical activity and sedentary behaviorbehavior at baseline, the percentages of time spent in each intensity during weekend days, school days and afterschool periods were compared using ANOVAs (n=56). To examine the change over time separate linear mixed models with random intercepts were performed for weekend days, school days, and afterschool periods. All models were adjusted for weartime. Participants were only included in intervention analyses if they remained in the study for at least two assessment periods (n=49). To account for slight non-normality in the data, standard errors were bootstrapped with 1000 replications. All analyses were completed using Stata/IC 13.0 for Windows (StataCorp LP, College Station TX, USA). No explicit control for multiple comparisons was performed, rather 95% confidence intervals for all parameter estimates are presented together with actual p-values where appropriate.

For the EVA analysis, the mean percentage of time in each cell was computed and graphed at each timepoint. The mean daily minutes spent in each of the bout durations of 0 to 5 minutes, 5 to 10 minutes, 10 to 30 minutes, 30 to 60 minutes and greater than 60 minutes were compared across time using separate mixed models for each intensity level (sedentary, light, moderate, and vigorous) similar to the models used to evaluate changes in the primary outcomes across time described above. To illustrate the potential utility of EVA for describing inter-individual variation and the differential changes in bout durations, two individuals (one *More Active* individual with the greatest increase in MVPA following intervention and the other *Less Sedentary* individual with the greatest decrease in sedentary time) were selected for brief case studies. Their individual EVAs from baseline and 12 months are presented.

Results

Patterns by Time and Type of Day

The overall physical activity at baseline and during afterschool, weekends, and school day periods can be seen in Table 1. Participants spent a lower percentage of time in light physical activity during school days (25.5%) compared to weekend days (25.5% vs. (29.0%, p=.004). Conversely, participants spent a lower percentage of time in sustained bouts of sedentary behavior on weekends (21.8%) compared to school days (27.4%) but this was not statistically significant. The change in total physical activity during the intervention has been previously reported,[6] and there were small but statistically significant improvements in sedentary and moderate activity during the intervention compared to the waitlist period.

Afterschool period. During the waitlist period, moderate physical activity decreased (-2.6 minutes per day, 95%CI: -4.4, -0.9, p=.004). During the intervention period, moderate physical activity increased (2.3 minutes per day, 95% CI: 0.2, 4.4, p=.031). The rate of change during the intervention period (1.1 minutes/day/month, 95% CI: 0.1, 2.2) was significantly greater (p=.004) than the rate of change during the waitlist period (-0.9 minutes/day/month, 95% CI: -1.5, -0.3). There were no significant changes in sedentary, light or vigorous activity during the afterschool period following the intervention.

School Days. During the waitlist period, sedentary time increased (13.7 minutes per day, 95% CI: 1.2, 26.1) and light physical activity decreased (12.2 minutes per day, 95% CI, 1.3, 23.0). During the intervention period, sedentary time decreased (-9.0 minutes per day, 95% CI: -22.1, 4.2) and light physical activity increased (4.8 minutes per day, 95% CI: -7.0, 16.6), however these were not significantly different from the change during the waitlist period (p=.18 and .42 respectively).

Weekend Days. There were no significant changes in any physical activity intensity during weekend days following the intervention. The differences between school days and weekend days over the study period can be seen in Figure 1.

Breaks and Bouts Patterns

There were no differences in sedentary breaks across the intervention. A detailed analysis of uninterrupted bouts of activity at each intensity level at baseline can be seen in Figure 2.

At baseline, two thirds of sedentary time was spent in bouts of at least 10 mins or more, and over three quarters of MVPA occurred in bouts of 5 minutes or less (see Table 2). There were few to no bouts of sustained moderate or vigorous physical activity greater than 5 minutes. This pattern was consistent for afterschool, school days and weekend days.

During the maintenance period, there was evidence of a shift towards longer uninterrupted bouts of sedentary time during school days with an increase in the average minutes spent in bouts greater than 60 minutes at 3 months (69.8 minutes per day, SE 7.8) and 6 months (69.5 minutes per day, SE 7.9) compared to pre-intervention (50.2 minutes per day, SE 4.1, p=.028 and p=.029 respectively). This shift was even more prominent during the weekends. The number of minutes spent in uninterrupted sedentary bouts increased during the maintenance period from 146.4 (SE 10.5) minutes per day during pre-intervention to 206.3 (SE 20.1, p = 0.01) minutes per day at three months, and 196.5 (SE 20.7, p=.035) minutes per day at 12 months.

Case Analysis

To examine individual changes in patterns of physical activity and sedentary time, EVAs were examined for two individuals. The patterns of activity for each individual can be seen in Figure 3. Both participants had patterns similar to the total sample at baseline. However, the patterns at 12-months post-intervention are unique. The *More Active* individual increased total MVPA by 40 minutes per day (sedentary time also increased by 78.2 minutes per day). This *More Active* individual had small increases in the percentage of time spent in moderate bouts of 10-30 minutes (see thin arrow in Figure 3) and still had a high percentage of time in longer sedentary bouts (18 percent of time spent in 30 minute bouts or longer at baseline and 20 percent of time at 12 months) as shown in Figure 3. The *Less Sedentary* individual decreased total sedentary time by 134.6 minutes per day (also increased MVPA by 4.2 minutes per day). This *Less Sedentary* participant decreased sedentary bouts of greater than 30 minutes (15.9 percent of total time at baseline to 8.2 percent of total time – see large arrow on Figure 3) and increased the percentage of time spent in bouts of light physical activity, especially bouts of 10-30 minutes (8.5 percent of total time at baseline to 15.9 percent of total time at 12-months post-intervention – see thin arrows on Figure 3).

Discussion

This analysis provides an example of a novel way to use objective accelerometry measures to examine detailed patterns of overweight and obese adolescents' physical activity and sedentary time. Further, this analysis was able to show small and specific changes in these patterns while participating in a family-centered, community-based, lifestyle intervention.

Patterns by Time and Type of Day. The participants had similarly low levels of activity and high sedentary time during weekdays, school days and the afterschool period, though adolescents participated in a slightly greater percentage of light activity on the weekends. This is similar to Laguna et al. who also found no difference between weekend and week days for overweight adolescents. While select studies have found overweight adolescents to be less active on weekends,[13,14] the overall low levels of physical activity in overweight adolescents[1] may attenuate the day of week effects. Thus it is important to target both weekend and weekdays among overweight and obese adolescents. The current findings also showed that during the afterschool period tThere was also less time spent in longer uninterrupted bouts of sedentary time during the afterschool period. However, this may be an artifact of the shorter measurement time (two and a half hours) compared to the full day (13 hours), thus limiting longer bouts of time.

During the intervention, improvements in physical activity and sedentary time were seen during school days and the afterschool period, while there were no significant changes during the weekends. This suggests that the participants made most of their positive changes in physical activity and sedentary time during the afterschool period. This was consistent with the structure of the intervention and suggestions for participants to join structured exercise classes (e.g. aerobics, dance or martial arts) or schedule regular physical activity into this time period (e.g. participating in active transport from school). Future research needs to work with overweight and obese adolescents to identify acceptable and enjoyable activities for the weekends.

Breaks and Bouts Patterns. In addition to the differences between days of the week and time of the day, this study also examined patterns in terms of the breaks in sedentary time and bouts of ~~physical activity and~~ sedentary, light, moderate and vigorous time of overweight and obese adolescents. The majority of time was spent in longer bouts of sedentary time and the time spent in light to moderate activity was usually in short bouts of less than 5 minutes. Both the breaks in sedentary time and sedentary bouts are indicative of a harmful behavioral pattern of uninterrupted sedentary time. The adolescents in the current study averaged eight breaks in sedentary time per hour which was only slightly less than nine breaks per hour in a sample of 10-12 year old Australian children.[23] Unfortunately, there were no changes in the number of breaks following the intervention, suggesting that participants did not break up their sedentary time more often. The pattern of ~~physical activity~~sedentary bouts seen in these overweight and obese adolescents was similar to that of office workers, who have a largely sedentary occupation that is recognized to have harmful health effects~~.~~[22] ~~The majority of time was spent in longer bouts of sedentary time and the time spent in light to moderate activity was usually in short bouts of less than 5 minutes.~~ The adolescent participants in this study spent more than three hours on average per day in uninterrupted sedentary bouts greater than 30 minutes, which was greater than the two hour average of ~~a sample of 10-12 year old~~ younger any weight status Australian children~~,~~[23] This exposure to prolonged sedentary bouts has potential negative health implications,.[17,18,20] although experimental evidence suggests it may be less critical in children.[21]

In comparison to sedentary time, physical activity bouts were brief. This confirms expectations that this population is unlikely to engage in long durations of exercise or intentional physical activity and the majority of their physical activity will occur through incidental activity in shorter bouts. While previous physical activity recommendations have suggested that MVPA~~physical activity~~ should be accumulated in bouts greater than 10 minutes,[33] emerging research has shown that incidental physical activity that occurs in bouts less than 10 minutes may also be beneficial for health[34] including weight status in adults,[35,36] especially when it occurs across the day.[15] This is positive as overweight and obese adolescents appear less likely to accumulate longer bouts of MVPA. It is possible that adolescents may need longer bouts of physical activity (greater than four minutes) to confer substantial benefits.[32] If adolescents require longer bouts to receive health benefits, increased efforts to extend bout durations will be needed.

Unfortunately, participating in a community, family-based lifestyle intervention did not increase the amount of time spent in longer bouts of physical activity or reduce the amount of time spent in uninterrupted bouts of sedentary time, despite targeting improvements in these behaviors. Future research is needed on better strategies to break-up extended sedentary bouts in overweight and obese adolescents.

Individual Differences. While participation in the intervention resulted in small changes in overall physical activity patterns,[6] the examination of the two individuals' EVAs shows the unique ways of changing and potentially improving activity profiles. While one participant increased MVPA, the other decreased sedentary time by increasing light activity. It is still unknown which of these profiles confers better health benefits, however, evidence in adults suggests that displacing sedentary time with MVPA may be most beneficial, but light intensity activities also provides health benefits.[37] Based on this variation, individually tailored interventions, when delivered appropriately, may result in better health benefits, and be ideally suited for overweight and obese adolescents.[38]

Methodological Strengths and Limitations. The detailed EVA approach in this study can help to elucidate patterns of activity. This information can be used to design targeted intervention messages. For example, with the growth of text messaging and mobile app health interventions, timely, tailored messages could be targeted towards reducing long sedentary bouts on weekends. Additionally, EVA provides a way to visualize whole activity profiles that may aid in examining physical activity measurement issues (i.e. what happens to the entire spectrum of physical activity when alternate intensity cutpoints are used) as well as the conjoint effects of the amount of time spent in each energy band, and the distribution of bout lengths, on health outcomes. While EVA does provide a detailed description of the pattern of objectively measured physical activity and sedentary time, novel methods are needed to objectively capture the context of these activities. ~~This study included a sample of overweight and obese adolescents from urban and rural settings but additional studies are needed to confirm the generalizability of these physical patterns to other overweight and obese adolescent populations.~~ The small within-subject design was adequate for testing change within subjects across the intervention, but a larger sample is needed to confirm these physical activity and sedentary patterns are generalizable to broader overweight and obese populations. Additionally, a direct comparison of these detailed patterns between overweight and non-overweight adolescents would help to identify potential target behaviors for intervention.

Conclusion. Physical activity is a complicated behavior. A better understanding of it can help to design interventions that affect specific behaviors, with unique health consequences, that may lead to significant and meaningful behavior change. Targeted information may be most critical for populations with the lowest levels of physical activity and greatest health risks, including overweight and obese adolescents.

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EH carried out the analysis and drafted the manuscript. LS conceived of the study, and participated in its design and coordination and helped to draft the manuscript. TO, RA participated in the design of the study and interpretation of the results. JM participated in the analysis interpretation and drafting of the manuscript. All authors read and approved the final manuscript. The authors have no competing interests

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Table 1: Baseline activity details of participants

	Total	Afterschool	Weekend	SchoolDay	P-Value*
n (valid accelerometry)	56	51	51	55	
# of days worn	6.1 (1.3)	4.7 (1.1)	1.8 (0.5)	4.6 (1.1)	
Mean weartime (min/day)	779.0 (74.3)	149.5 (2.0)	726.5 (106.9)	800.3 (79.4)	
Sedentary (min/day)	547.4 (91.7)	100.6 (15.8)	493.8 (118.6)	569.0 (93.7)	
Light PA (min/day)	197.7 (54.0)	41.2 (12.3)	208.5 (74.7)	194.8 (52.4)	
Moderate PA (min/day)	32.6 (18.4)	7.2 (7.0)	22.6 (22.2)	35.2 (19.8)	
Vigorous PA (min/day)	1.5 (2.6)	0.5 (1.1)	1.6 (4.0)	1.3 (2.4)	
Sedentary time in bouts of ≥ 30 minutes (min/day)	207.9 (88.5)	30.3 (18.8)	176.0 (99.1)	220.2 (92.6)	
Sedentary % weartime	70.1	67.3	67.7	70.1	.138
Light PA % weartime	25.5	27.6	29.0	24.4	.019
Mod PA % weartime	4.3	4.8	3.2	4.5	.076
Vig PA % weartime	0.2	0.3	0.2	0.2	.527
Breaks (breaks/sedentary hr)	7.6	8.0	8.6	7.6	.096

Mean(standard deviation) or percent

*ANOVA comparing total, afterschool, weekend and school day percentages

Table 2: Baseline activity bout duration and intensity using exposure variation analysis

Intensity	**Time Spent in Bouts** *Mean min/day (SD)* *% intensity, % total*				
	<5 Minutes	5-10 Minutes	10-30 Minutes	30-60 Minutes	60+ Minutes
Sedentary	74.7 (16.0) 14.3, 9.7	75.2 (13.6) 14.3, 9.7	193.4 (39.4) 36.1, 24.9	146.1 (56.5) 26.2, 18.6	52.3 (42.1) 9.2, 6.6
Light	122.9 (19.0) 63.4, 15.9	50.0 (18.1) 24.5, 6.5	25.3 (21.7) 11.3, 3.3	1.8 (4.0) 0.8, 0.2	0.3 (2.3) 0.1, 0.04
Moderate	23.2 (12.3) 76.0, 3.1	5.8 (5.0) 15.2, 0.8	3.5 (5.2) 8.8, 0.5	0 0, 0	0 0, 0
Vigorous	1.3 (2.2) 94.8, 0.2	0.2 (0.6) 4.6, 0.03	0.03 (0.2) 0.6, 0	0 0, 0	0 0, 0

Figure 1: Percentage of mean daily time in bout duration (<5, 0-<10, 10-<30, 30-<60, ≥60) by activity intensity (sedentary, light, moderate, vigorous)

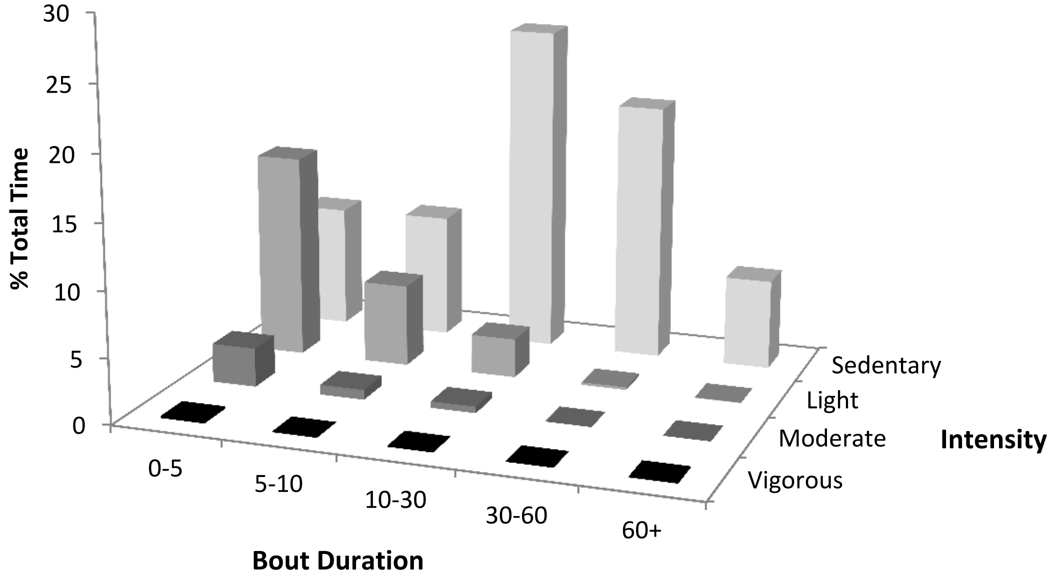
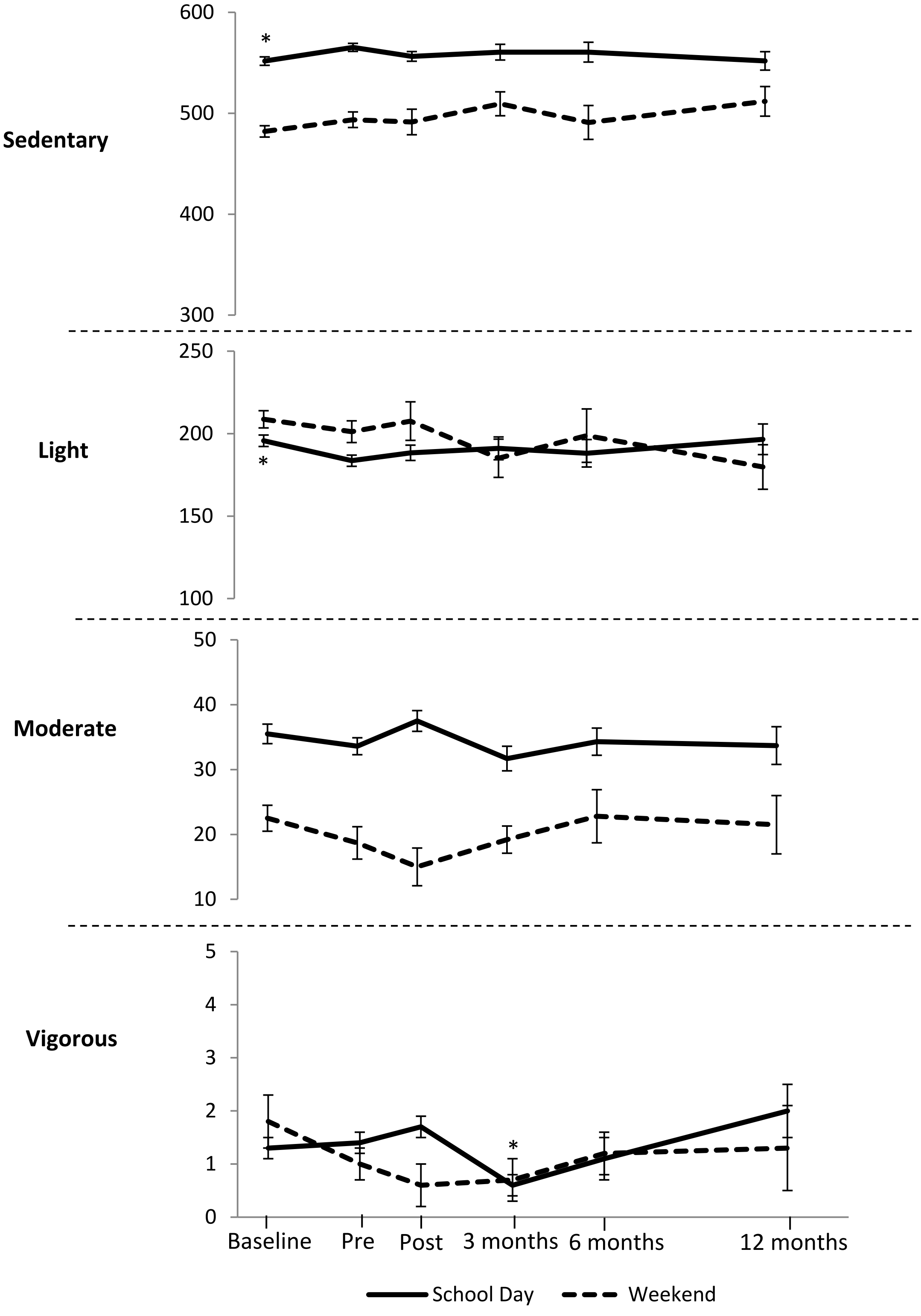


Figure 2: Mean minutes of activity (±SE) during baseline, intervention, and maintenance by weekend and school days



* difference from Pre at p<.05

Figure 3: Two individual's mean activity in bout durations and intensity pre- and 12 months post-intervention