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A multilevel approach to examining time-specific effects in accelerometer-assessed physical activity

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ABSTRACT

Objectives: Popular methods for analyzing accelerometer data often use a single physical activity outcome variable such as average-weekly or total physical activity. These approaches limit the types of research questions that can be answered and fail to utilize the detailed, time-specific information available from accelerometers. This study proposes the use of multilevel modeling, which tested intervention effects at specific time periods.
Design: The motivating example was the Active by Choice Today trial. Simulations were used to test whether the application of time-specific hypotheses about when physical activity intervention treatment effects were expected to occur (e.g., after-school hours) increased power to detect effects compared to traditional methods.
Methods: Six simulation conditions were tested: (1) no treatment effects (to test the type 1 error rate), (2) time-specific effects, but no traditionally-tested effects, (3) traditionally-tested effects, but no time-specific effects, and (4) combinations of traditional and time-specific effects in 3 proportions.
Results: Results showed the proposed multilevel approach demonstrated appropriate type 1 error rates and increased power to detect treatment effects during hypothesized times by 31–38 percentage points compared to traditional approaches. This was consistent across varying proportions of traditional versus time-specific effects, and there was no loss of power using the multilevel approach when only traditional effects were present.
Conclusions: The current study showed potential advantages of testing time-specific hypotheses about intervention effects using a multilevel time-specific approach. This approach may show intervention effects when traditional approaches do not. Future research should explore the application of this additional analytic tool for accelerometer physical activity estimates.

1. Introduction

Accelerometer estimates of physical activity (PA) provide a potentially more accurate and flexible alternative to subjective and criterion measures.[1–3] Commonly used accelerometer analysis techniques include reducing the information into a single estimate of PA (e.g., average daily minutes/counts, total minutes/counts).[4,5] This approach limits the types of research questions that can be answered and may result in reduced statistical power to find PA intervention treatment effects. While researchers have recommended a variety of analytic techniques capable of handling complex accelerometer data,[6,7] usage and application of these techniques has been lacking.

Commonly used accelerometer analysis techniques assume PA interventions will have an effect on overall PA averaged throughout the day and across the measurement period. Descriptive studies have demonstrated differences in activity patterns across times and days of the week.[8–10] It is reasonable to expect that some interventions will not have a consistent, global effect across the wear period and that researchers can make hypotheses about specific times of interest that relate to intervention goals (referred to as time-specific effects). One example is the Active by Choice Today (ACT) trial.[11,12] ACT was a school randomized controlled trial that tested the effects of a motivation plus behavioral skills intervention (versus health education only) on increasing PA in middle school students. The ACT intervention was delivered as an after-school

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program and included 60 min of group PA. This suggests a specific test of the hypothesis that students in treatment schools are more active during the after-school program time periods while the intervention is in progress as well as a secondary test for whether those effects generalized to positively impact PA outside of the program time. An alternative analytic method is needed to test these hypotheses.

In circumstances where time-specific effects are applicable researchers may benefit from testing specific hypotheses about when interventions are effective. Common analytic approaches are not able to test hypotheses about treatment effects on PA patterns across time periods.[8–10] Time-specific hypotheses may help researchers link intervention components to time-specific PA changes and contribute to the understanding of context and long-term behavior change.[13] Therefore, the first goal of the current study was to demonstrate a more flexible way to utilize accelerometer data that applied time-specific hypotheses about when PA changes would occur as motivated by the published ACT outcomes.[11]

One potential benefit of a time-specific approach is an expected increase in power to detect time-specific hypotheses about intervention effects. As traditional techniques use only a single summary score (e.g., average minutes), some changes in PA patterns across the measurement period are lost. The proposed test of time-specific hypotheses utilizes repeated accelerometer estimates of PA within each measurement period (scores during hypothesized and non-hypothesized times), using a random coefficient (multilevel model) approach.[14] In effect, the entire accelerometer wear period is broken into meaningful time intervals, and treatment effects are analyzed both within and between individuals. It is expected that the within-subjects comparison should increase power over traditional between-subjects approaches.

Thus, the aims of the current study were twofold: (1) to provide a motivating example testing time-specific treatment effects, and (2) to test differences in power to assess treatment effects of the time-specific versus traditional approaches using simulations. It was hypothesized that both the time-specific and traditional methods would show appropriate type-1 error rates. Because the time-specific approach evaluates intervention effects at specific time periods it was also hypothesized that this approach would show increased power to detect treatment effects compared to the traditional approach when the intervention effects occurred only during the specified hypothesized times. The time-specific approach was not hypothesized to increase power when the intervention's true effects were the same across all time periods. In reality intervention effects may be partially time-specific and partially generalized. To better understand when this approach may be beneficial 3 additional conditions were tested in which the proportion of the effect that was time-specific varied from 33% to 66%.

2. Methods

The use of a multilevel time-specific approach was illustrated with data from the ACT trial (aim 1) in order to frame the motivating rationale for the statistical simulations (aim 2). A detailed description of the ACT trial [12,15] and outcomes [11] have been published previously. Briefly, ACT was a one-year PA intervention involving 24 schools (12 control, 12 intervention, $n = 1431$) and was approved by the University of South Carolina Institutional Review Board. Students wore an Actical omni-directional accelerometer (Mini-Mitter, Bend, OR) for 7 days at baseline, midpoint (halfway through the academic year), and 2-weeks post-treatment. Each day of Actical data was divided into five intervals, which correspond to meaningful time blocks in the day (early morning, school hours, after school, evening, night). These intervals were 6–9am, 9am–2pm, 2–5pm, 5–8pm, and 8pm to midnight as was done in a previous national trial.[16] Therefore, there were 35 PA intervals (5 time intervals per day over 7 days) per measurement period. In other applications of the proposed multilevel time-specific approach, these intervals should be customized (in both the number and length) such that they are most applicable to the research questions and intervention being tested. Raw activity data were converted into time spent in MVPA defined as ≥3 METS (cut-point = 1500).[17]

In the ACT motivating example (aim 1), both the traditional model and the time-specific model were used to examine intervention effects with sex, race, BMI, and baseline MVPA as covariates and an additional random effect to account for clustering of students within schools (see Supplement 1 for equations). The 35 intervals of MVPA at the midpoint assessment period were specified as the outcomes in the time-specific model, and it was expected that the intervention effects would be shown during the times the ACT after-school program took place (2–5pm on Monday, Tuesday, and Thursday). The ACT data were not transformed in order to retain the meaningfulness of the metric of PA minutes and are reproduced using minutes to be consistent with the published outcome data. [11] Secondary analyses using transformed data showed no differences.

The simulated PA data (aim 2) were modeled after ACT (35 intervals nested within child). The simulations evaluated the performance of the two analytic approaches following the motivating example: (1) the commonly used general linear model (equivalent to an ANOVA) shown in Eq. (1) (assessing differences between treatment conditions in average MVPA) and (2) a time-specific multilevel model shown in Eq. (2) (with a dichotomous hypothesized time (HypTime) indicator coded '1' if the specific time interval is expected to show within child treatment effects and '0' otherwise, and a between child treatment effect). Equations are given below using mixed multilevel notation and included no covariates[14]:

$$Y_i = B_0 + B_1 \mathrm{TX} + r_i \sim N(0, \sigma^2) \quad (1)$$

$$Y_{ti} = \gamma_{00} + \gamma_{10}\mathrm{HypTime}_{ti} + \gamma_{01}\mathrm{TX}_i + \gamma_{11}\mathrm{HyptTime}_{ti}\mathrm{TX}_i + \mu_{0i} + \mu_{1i}\mathrm{HypTime}_{ti} + r_{ti}$$
$$\text{where : } \mu_{0i}, \mu_{1i} \sim N(0, \tau), r_{ti} \sim N(0, \sigma^2) \quad (2)$$

where TX is a treatment indicator coded 0/1. There are $t = 1, \ldots, n_i$ time intervals (level-1) nested within $i = 1, \ldots, I$ individuals (level-2). Using the traditional method, the effect of interest is B_1 in Eq. (1) (the average difference in MVPA between treatment and control). Using the time-specific approach in Eq. (2) there are two effects of interest:, γ_{01} is the average difference in MVPA between treatment and control conditions averaged across all time points (a between person effect) and γ_{11} is the additional treatment effect specific to the hypothesized time periods versus all other times (a within person effect). In this case, the HYPtime variable was coded '1' on 2–5pm every day to reflect the applicable time-specific hypotheses and was generalized across all days (rather than the 3 ACT program days) in order to simplify the simulations. It should be noted that the proposed time-specific approach would be able to accommodate different effects across times and days consistent with the specific research questions and intervention. The traditional approach is subsumed by the time-specific approach when all time intervals are coded to show treatment effects (as hypothesized times).

For simplicity data were generated for an individually randomized rather than group randomized trial with 200 students per treatment condition to reflect sample sizes common in individually randomized interventions. For the purposes of the simulations, data