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Re-evaluating the effect of age on physical activity over the lifespan

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ABSTRACT

Advancements in accelerometer analytic and visualization techniques allow researchers to more precisely identify and compare critical periods of physical activity (PA) decline by age across the lifespan, and describe how daily PA patterns may vary across age groups. We used accelerometer data from the 2003–2006 cohorts of the National Health and Nutrition Examination Survey (NHANES) (n = 12,529) to quantify total PA as well as PA by intensity across the lifespan using sex-stratified, age specific percentile curves constructed using generalized additive models. We additionally estimated minute-to-minute diurnal PA using smoothed bivariate surfaces. We found that from childhood to adolescence (ages 6–19) across sex, PA is sharply lower by age partially due to a later initiation of morning PA. Total PA levels, at age 19 are comparable to levels at age 60. Contrary to prior evidence, during young adulthood (ages 20–30) total and light intensity PA increases by age and then stabilizes during midlife (ages 31–59) partially due to an earlier initiation of morning PA. We additionally found that males compared to females have an earlier lowering in PA by age at midlife and lower total PA, higher sedentary behavior, and lower light intensity PA in older adulthood; these trends seem to be driven by lower PA in the afternoon compared to females. Our results suggest a re-evaluation of how emerging adulthood may affect PA levels and the importance of considering time of day and sex differences when developing PA interventions.

1. Introduction

While greater physical activity (PA) (Caspersen et al., 1985) has been linked to a broad range of beneficial health outcomes across the lifespan (Anon., 2010), the majority of Americans do not meet PA guidelines (Anon., 2008; Troiano et al., 2008). One of the most consistently reported risk factors associated with decreased PA is age. Prior research indicates an almost universal decline in PA throughout the lifespan, with critical periods at childhood (ages 6–11 years) and adolescence (ages 11–19 years) (Troiano et al., 2008; Sallis, 2000; Wolff-Hughes et al., 2015). Emerging adulthood (ages 18–30) has also shown to be associated with a decline in PA (Brown & Trost, 2003; Corder et al., 2009); some evidence suggests that PA may stabilize during midlife (Caspersen et al., 2000; Hyde et al., 2013) and then decline again at older ages (DiPietro, 2001).

Age-related decline in PA is driven by physiological, psychosocial, and environmental factors. For example, the dramatic decline during childhood and adolescence is driven partially by physiology/development (e.g., shift to a later chronotype (Hagenauer et al., 2009; Roenneberg et al., 2004)) and environment (e.g., decrease in school-based PA (Racette et al., 2010; Anon., 2011)). Declines during emerging adulthood may be driven by psychosocial factors, including life transitions (e.g., completion of mandatory schooling and full time work (Brown & Trost, 2003; Corder et al., 2009)), and declines at older ages are driven be chronic disease morbidity (DiPietro, 2001) and environmental factors related to safety and accessibility (Moran et al., 2014). These effects may also vary by sex during childhood and adolescence due to differences in motivation, interests (Azevedo et al., 2007), and access to sports participation (Deaner et al., 2012). Effects may vary during later life due to differences in chronic disease prevalence (Ward & Schiller, 2013), frailty (Walston & Fried, 1999), and fall risk (Stahl & Albert, 2015).

While age, sex, and many associated physiologic factors are not modifiable, a number of factors that contribute to declines across the lifespan are potentially modifiable, including environmental factors (Foster & Hillsdon, 2004; Humpel et al., 2002). The explicit goal of public health researchers in understanding age-related declines and differences in PA across age groups is to identify age groups that are at higher and lower risk. This can lead to further investigations of specific factors contributing to PA levels and designing specific interventions targeting those factors and age groups.

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Advancements in accelerometer analytic and visualization techniques (Troiano et al., 2014) allow researchers to better understand demographic trends across the lifespan and differences in PA across age groups. Insights gained from these analyses can clarify demographic trends in PA and more clearly identify high-risk groups. Additionally, recently developed methods that move beyond average activity and describe and quantify minute-by-minute daily activity patterns (Schrack et al., 2014; Xiao et al., 2015) may provide critical insights into what may drive PA differences across age groups; this in turn can lead to age-specific, tailored interventions.

This study used the pooled accelerometer data from the 2003–2004 and 2005–2006 cycles of the National Health and Nutrition Examination Survey (NHANES) to identify and compare critical periods of PA decline by age and sex across the lifespan, and describe how daily PA patterns may vary across age groups.

2. Methods

2.1. Study sample

The NHANES is a cross-sectional, nationally representative survey that assesses demographic, dietary and health-related questions and can be used to better understand differences in health and nutrition across age groups (Centers for Disease Countrol and Prevention, 2014). Survey data are made publically available by the National Center for Health Statistics (NCHS). All individuals participating in data collection provided informed consent, and the NCHS Ethics Review Board approved all survey protocols.

2.2. Accelerometer data collection and processing

The 2003–2004 and 2004–2005 survey cycles (2003–2006) collected accelerometer data for 7 consecutive days on individuals aged 6 years and older who were ambulatory (Troiano et al., 2008). The Actigraph AM-7164 (Actigraph, Ft. Walton Beach, FL) uni-axial accelerometer was placed on an elastic belt and participants were instructed to wear the device on the right hip at all times other than during any aquatic activity, including swimming and bathing, and at bedtime (Troiano et al., 2008). After completing data collection protocol, participants were instructed to return the device by mail.

The Actigraph accelerometer recorded movement intensity values, or activity counts, at 1-min epochs; the NCHS and survey collaborators performed initial data review for outliers and unreasonable values.

Similar to previous studies (Troiano et al., 2014; Choi et al., 2011) a criteria of at least 90 consecutive minutes of zero counts, with allowance for up to two consecutive minutes with up to 100 counts, was used to determine non-wear time; days with >14 h of non-wear time were excluded. The final sample included 12,529 individuals.

We explored PA in 5 age groups associated in prior studies (e.g., (Anon., 2011; Johnson et al., 2013)) with distinct transitions across the lifespan: children (ages 6–11); adolescents (ages 12–19); young adults (ages 20–30); adults at midlife (ages 31–59); and older adults post retirement (60+).

2.3. Measures and statistical analysis

Data was analyzed in 2016. Minute level activity counts were log-transformed by applying log(1 + activity counts) resulting in the log-transformed activity counts (LAC). This transformation has the advantage that minutes with 0 activity counts are transformed into 0 counts on the natural log scale and the severely skewed nature of the counts data is dramatically reduced (Schrack et al., 2014; Xiao et al., 2016). The total log-transformed activity counts (TLACs) were then obtained by summing LACs over all minutes during the day. Daily TLAC was used as a measure of total volume of daily PA. Prior studies exploring accelerometer measured PA across the lifespan (Wolff-Hughes et al., 2015; Wolff-Hughes et al., 2014) have relied on total (non-transformed) activity counts, which result in a highly skewed measure of PA. Appendix Fig. A displays the quantile plot and the histogram of daily TLACs for all subjects and indicates that TLAC follows a normal distribution.

The sex-stratified, age-specific percentiles curves of the TLAC were constructed using generalized additive models for location, scale and shape (GAMLSS) implementation (Stasinopoulos & Rigby, 2007) of Lambda-Mu-Sigma (LMS) method (Cole & Green, 1992) that was originally introduced for constructing child growth charts. Briefly, the LMS method transforms data for each age using a Box-Cox transformation under the assumption that the parameters of transformation changes smoothly with age; the transformed data is assumed to follow a known distribution (such as normal or t-distribution) and quantiles are fitted to the transformed data and then mapped back to the original scale. The LMS model was fitted using survey weighted penalized likelihood (Stasinopoulos & Rigby, 2007). For computational stability, the survey weights were normalized to sum up to the sample size. Among Box-Cox Cole-Green distribution, Box-Cox Power Exponential distribution, and Box-Cox T distribution (BCT), the latter was chosen as optimal based on the global deviance criteria (Rigby & Stasinopoulos, 2006). Because of a large number of zeros, we used zero-adjusted GAMMA (ZAGA) distribution in modeling MVPA curves. The goodness-of-fit of the optimal-transformation, LMS-BCT, was investigated by testing fit over the age range of 6–84 via Q-statistics that test normality of the residuals through the first four central moments (mean, variance, skewness, and kurtosis) (Stasinopoulos & Rigby, 2007). Similarly, the age-specific percentiles curves for the time spent in sedentary PA (SePA), light PA (LiPA), and moderate-to-vigorous PA (MVPA) were constructed using the methods described above. The standard NHANES cut-off points were used to define sedentary PA (AC less than or equal 100), light PA (AC between 101 and 2019) and moderate-to-vigorous PA (AC above 2020) (Troiano et al., 2008). In order to statistically test patterns observed in Figs. 1, 2, and 3, we split the lifespan (6–84) into 6-year increments (13 age groups) and modeled TLAC, SePA, LiPA, and MVPA as outcomes in regression models with covariates including sex, age, and the interaction of sex and age. The group 17–22 year old females was chosen as the reference group because it contains the PA low indicated in Fig. 1. The model is as follows:

$$Y_i = g_F + g_M I_{\{Gender_i = Male\}} + \sum_{l=1}^{12} a_l I_{\{Age_i \in Age^l\}} + \sum_{l=1}^{12} g a_l I_{\{Age_i \in Age^l\}} I_{\{Gender_i = Male\}},$$

where Y_i denotes the outcome (TLAC, SePA, LiPA, or MVPA) of the i-th NHANES participant having $Gender_i$ and Age_i. The estimated models were used to calculate the gender and age-specific fitted values as follows: i) g_F and $g_F + g_M$ estimate the female and male effects in the 17–22 year old reference group, respectively; ii) $g_F + a_l$ and $g_F + g_M + a_l + g a_l$ estimate the female and male effects in the Age^l age group, respectively. The model estimates and statistically tests the significance of the sex, age, and sex-by-age effects. The models were fit using the R package "survey" (Lumley, 2011) that accounts for the complex design of NHANES.

The age-specific changes in diurnal patterns of PA were estimated via average time-of-day by age bivariate surfaces of LAC. Specifically, subject-specific diurnal profiles of ten-minute LACs were survey-weighted and ordered by age and a bivariate spline smoother (Xiao et al., 2015) was applied. The optimal smoothing parameters were determined using leave-one-subject-out cross validation.

3. Results

Demographic characteristics of the U.S. population representative sample surveyed using NHANES accelerometer data for each of the