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Combinations of light, moderate, and vigorous physical activity in midlife and old age: implications for healthy cognitive aging

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Abstract

Background: Although the relationship between physical activity (PA) and healthy cognitive aging is well-established, little is known about how different combinations of PA across intensities and life domains may uniquely buffer against declines in cognitive health.

Purpose: This study examined the role of modifiable profiles of light, moderate, and vigorous PA that may operate in tandem across domains to protect cognition in midlife and old age.

Methods: Using prospective 9-year data from the Midlife in the United States Study ($n = 2688$; $M_{age} = 55 \pm 11$ years), we employed factor mixture models to identify baseline profiles (combinations) of light, moderate, and vigorous PA in the domains of work, home, and leisure. We subsequently examined profile differences in 9-year trajectories of cognitive aging across 2-waves of data using autoregressive analyses of covariance (ANCOVAs).

Results: Factor mixture model results showed that 5 common profiles emerged: low PA, low work PA, average PA, balanced PA, and high PA. Autoregressive ANCOVAs showed the balanced PA profile, which paired very high levels of light PA with relatively average levels of moderate and vigorous PA, experienced less decline in executive functioning than the low PA ($P = .038$) and low work PA profiles ($P = .001$). Contextualized effect sizes suggested that rates of 9-year decline in executive functioning for the balanced PA profile were reduced by more than 25% relative to the low PA and low work PA profiles.

Conclusions: Findings suggest that balanced PA across life domains, with an emphasis on maintaining light PA, may help slow age-related cognitive declines in midlife and old age.

Key words: physical activity profiles; modifiable health behavior; person-centered approach; healthy cognitive aging; longitudinal

Lay Summary

People differ in the rate at which their cognitive functioning worsens with age. Those who engage in more frequent physical activity generally have slower rates of decline. However, little was known about people's typical patterns or combinations of light (eg, easy walking, light housework), moderate (eg, brisk walking), and vigorous (eg, running) physical activity and how these patterns may be linked to rates of cognitive aging. This study found that middle-aged and older adults who combined frequent light physical activity with infrequent exercise experienced the slowest rates of cognitive decline over a 9-year period.

Introduction

Decades of evidence point to physical activity (PA) as a core health behavior that facilitates successful aging by reducing risk of cardiovascular disease, frailty, and cognitive decline or impairment.[1-6] For example, although some heterogeneity in effects has been observed, meta-analyses of randomized control trials and prospective observational studies have generally shown that PA, ranging in intensity from light to vigorous, decelerates cognitive declines and reduces risk of cognitive impairment over time periods of up to 25 years.[6-11] While links between PA of all intensities and cognitive aging are well documented, little remains known about how different combinations of light, moderate, and vigorous PA across life domains may uniquely buffer against cognitive declines in midlife and old age. There is an urgent need for research on such multidimensional health behaviors that are amenable to change. This is because rates of dementia will triple by 2060 in the absence of major advances in scientific knowledge of modifiable, real-world factors that can be targeted using evidence-based interventions to buffer against cognitive declines.[12] The present study thus used data from the national Midlife in the United States (MIDUS) Study to (1) identify common combinations or profiles of light, moderate, and vigorous PA in multiple life domains and (2) prospectively document profile differences in 9-year cognitive functioning.

Light PAs have metabolic equivalent of task (MET) values of 1.6-2.9 and include light walking and washing dishes, whereas moderate PAs range from 3.0 to 5.9 METs and include brisk walking and vacuuming, and vigorous PAs have MET values ≥ 6.0 and include running and carrying heavy objects.[13,14] Decades of research support the link between higher intensity moderate or vigorous PAs and healthier cognitive aging. Seminal research by Yoshitake et al[15] documented that older Japanese adults with high levels of moderate or vigorous PA had a reduced risk of developing dementia over a 7-year follow-up. Similar results were observed in subsequent national studies from the United States, the United Kingdom, and Australia that found higher moderate or vigorous PA was prospectively linked to slower rates of cognitive decline and a reduced risk of cognitive impairment over extended follow-up periods.[4,16–18]

Growing evidence suggests that lower intensity (lighter) types of PA are also linked to better cognitive health.[7] Early research by Laurin et al[19] found that higher levels of light PA predicted reduced risk of 5-year cognitive impairment in a national sample of older Canadians when controlling moderate-to-vigorous PA. This work was replicated in subsequent studies that found older adults with higher light PA were at lower risk of impairment over 2-8 year follow-up periods.[20–23] Recent research based on a national US sample extended this work by showing that light PA predicted slower rates of subclinical declines in more sensitive indicators of healthy cognitive aging: Findings showed light PA predicted 9-year trajectories of episodic memory and executive functioning, even when controlling for moderate and vigorous PA.[24]

These findings based on variable-centered approaches such as regression offer some insight into how individual differences in light to vigorous PAs can independently affect cognitive aging. However, many individuals engage in multiple forms of PA as part of their daily activities at work and home, which suggests that frequency of light, moderate, and vigorous PAs are likely to exist in multifaceted combinations rather than in isolation.[22,24,25] For example, some individuals are likely to engage in frequent light PA, frequent moderate PA, and frequent vigorous PA, whereas others may engage in frequent light PA, but infrequently engage in moderate or vigorous PA. Variable-centered approaches such as regression or multilevel modeling are not well-suited to capture the nuanced ecological reality that individuals differ in their patterns or profiles of light, moderate, and vigorous PA frequency because such approaches treat different forms of PA as competing predictor variables. This contrasts with person-centered approaches such as latent profile analysis or factor mixture modeling that treat light, moderate, and vigorous PA as complementary variables that coexist in meaningful combinations (PA profiles) and may better predict cognitive aging.[26,27] Open questions thus remain regarding (1) how frequency of light, moderate, and vigorous PA across multiple life domains combine to form rich combinations or profiles of PA in midlife and old age and (2) the extent to which such profiles have implications for healthy cognitive aging over extended time periods.

Using 9-year data from the national MIDUS study, our study adopted a person-centered approach to identify individual differences in common combinations (profiles) of light, moderate, and vigorous PA in midlife and old age. These combinations were identified based on PA in multiple life domains that included work, home, and leisure. We subsequently examined profile differences in 2-wave, 9-year trajectories of cognitive aging. Our focus was on longitudinal changes in central indicators of cognitive functioning shown to be sensitive to early age-related declines: episodic memory and executive functioning.[28]

We expected profiles that combined high levels of light, moderate, and vigorous PA across domains to buffer against cognitive declines relative to profiles characterized by low levels of PA.[6–10] We also expected to observe compensatory effects for profiles that combined low PA at certain intensities or in select domains with high PA at other intensities or domains. For example, modest levels of moderate or vigorous PA, which is not uncommon in midlife and old age, may be compensated for with high levels of light PA that can also protect against cognitive declines.[24,29] Further, the detriments of low levels of light PA could be offset by maintaining high levels of moderate or vigorous PA.[30] Compensatory effects may also be observed across domains.[31] For instance, some individuals may engage in limited PA at work or home but make up for this inactivity with high levels of PA during their leisure time, which could also buffer against age-related cognitive declines. Finally, the present study explored whether profile differences in cognitive aging trajectories depended on (were moderated by) key demographic characteristics including age, sex, race, education, and income.

Methods

Participants and procedures

We examined our research questions using data from the MIDUS National Longitudinal Study of Health and Well-being. A detailed summary of MIDUS can be found elsewhere.[32,33] Briefly, MIDUS is an ongoing national study of US adults who were 25-75 years old at baseline assessment (1995). Participants were recruited via random digit dial probability sampling of US households with at least one telephone in the contiguous states, stratified by age with oversampling of individuals aged 40-60 years. Eligible participants were noninstitutionalized adults aged 25-75 who were proficient in English. Baseline data were assessed in 1995 (Wave 1; $n = 7108$), and all willing participants were reassessed in 2004 (Wave 2; $n = 4963$) and 2013 (Wave 3; $n = 3294$). At Wave 2, an oversample of 592 Black Americans residing in Milwaukee, WI were recruited into the MIDUS study. The current study focused on participants from Waves 2 and 3 because (1) data were not collected for the Milwaukee oversample at Wave 1 and (2) cognitive functioning was not assessed for any sample at Wave 1.

Inclusion criteria for the present study were that participants provided data at Wave 2 on our indicator variables for the latent profiles (light, moderate, and vigorous PA) and at Waves 2 and 3 for a least one of our outcome measures (episodic memory, executive functioning). These criteria allowed us to examine how profiles of PA predicted 9-year changes in cognitive functioning. Written informed consent was obtained from all participants prior to participation.

Midlife in the United States data collection was approved by the Education and Social/Behavioral Sciences and the Health Sciences Institutional Review Boards at the University of Wisconsin-Madison.

Study measures

Physical activity

Frequency of light, moderate, and vigorous PA were assessed in MIDUS at Wave 2 with a new 18-item measure that was similar to other self-report measures, such as the International Physical Activity Questionnaire.[34] Participants responded to each item using a 6-point scale (1 = several times a week, 2 = once a week, 3 = several times a month, 4 = once a month, 5 = less than once a month, 6 = never). We reverse coded all items so that higher scores reflected more frequent PA. Participants reported how frequently they participated in light PA (eg, easy walking, light housework, fishing), moderate PA (eg, brisk walking, low impact aerobics), and vigorous PA (eg, running, lifting heavy objects) during summer and winter and in work, home, and leisure settings. Items thus captured frequency of light, moderate, and vigorous PA across multiple domains and seasons.

We created domain-specific continuous measures of light, moderate, and vigorous PA at Wave 2 building on the approach developed by Lachman et al.[35,36] For example, for light PA, we generated composite measures of PA that averaged participants' scores across the summer and winter seasons. We thus generated 3 scores that captured participants' light PA in the domains of work, home, and leisure (ie, light PA at work, light PA at home, light PA at leisure). The same approach was used to create 3 domain-specific moderate PA scores and 3 domain-specific vigorous PA scores (see Table S1 for a summary of the zero-order correlations between the study variables).

Previous research supports the reliability of these PA measures in documenting high levels of internal consistency for the moderate and vigorous PA items (αs = .80-.92).[35,37] Cotter and Lachman's study[35] also supported the validity of these PA measure by documenting that the proportion of MIDUS participants within each activity classification (inactive, not regularly active, regularly active) was relatively consistent with national estimates from the Centers for Disease Control and Prevention (CDC). They observed slight overestimates of inactivity because MIDUS did not assess PA in spring and fall when activity levels may be higher. Recent research[38] further supports the validity of these PA measures in documenting that levels of PA in MIDUS were similar to those observed in other population-based studies that include: the US Health and Retirement Study, the English Longitudinal Study on Aging, and the Longitudinal Internet Study for the Social Sciences from the Netherlands (see the Supplementary Material for further detail). Taken together, these findings indicate that (1) the PA measures employed in MIDUS yield estimates of PA that are broadly in line with CDC estimates, as well as those observed in other population-based studies that have utilized a range of other established self-report PA measures and (2) MIDUS estimates of PA may be slightly conservative due to the assessment of PA in only summer and winter.

Cognitive function

The Brief Test of Adult Cognition by Telephone (BTACT) was used to assess episodic memory and executive functioning at Waves 2 and 3.[39,40] Previous research with middle-aged and older adults has shown the BTACT to be a reliable and valid measure of central dimensions of cognition involving episodic memory and executive functioning.[40–42] A detailed summary of the BTACT can be found elsewhere.[28,42,43]

The BTACT battery includes 2 cognitive tests to assess episodic memory and 5 tests to evaluate executive functioning.[42] Episodic memory was assessed using immediate and delayed recall tasks (free recall of 15 words). Executive functioning was assessed using measures of inductive reasoning (completing patterns in a number series), category verbal fluency (number of animal names produced in one minute), working memory span (backward digit span), processing speed (number of digits produced counting backwards from 100 in 30 seconds), and attention switching and inhibitory control (Stop and Go Switch Task). The Stop and Go Switch Task comprised a reaction time test involving normal (respond GO to stimulus GREEN and STOP to stimulus RED) and reverse conditions (respond STOP to stimulus GREEN and GO to stimulus RED).[44] For the executive functioning measure, we used a recommended filter that retained data for only participants with valid scores on the Stop and Go Switch Task.[42,44] Valid scores were those in which there were no technical malfunctions, the participant understood the task, and the participant was not distracted by external events. Measures of episodic memory and executive functioning factors were calculated by averaging the standardized values of their respective subtests at each wave.[28]

Due to the nature of our 2-wave longitudinal data, we generated our primary outcome measures of regressed (residualized) change in episodic memory and executive function by regressing Wave 3 scores on the corresponding baseline (Wave 2) levels of each measure.[45–47] Residuals from these analyses were saved and used as indicators of regressed, longitudinal change in episodic memory and executive functioning.[45] Scores of 0 on our regressed change measures roughly reflect average (expected) sample rates of 9-year decline in episodic memory (raw decline $M = -0.120$) and executive functioning (raw decline $M = -0.257$). Positive values indicate less decline than expected in this sample, and negative values indicate steeper (more) decline than expected.

Demographic covariates

Age, sex, race, education, income, and self-reported physical health are well-established correlates of PA and cognitive functioning and were included as covariates in the main analyses.[24,28,36,42,48] Age in years was assessed at Wave 2. Race (0 = White, 1 = non-White) was assessed at Wave 1. Sex (1 = male, 2 = female) was assessed at Wave 1 and Wave 2, but scores were constant. We thus used race and sex data from the point of first assessment (Wave 1) to minimize missing data. Level of formal education completed (1 = no school or grade school, 12 = doctoral degree; see the Supplementary Material for further detail) and total household income in US dollars were assessed as continuous variables at Wave 2 in line with previous research.[24,36] Physical health status was assessed at Wave 2 using a 5-point scale (1 = excellent, 5 = poor), which was reverse-scored so that higher scores indicated better health.

Rationale for analyses

Analyses were conducted in a stepwise fashion. Step 1 involved person-centered, factor mixture models (FMMs) to identify subgroups of individuals with similar patterns of PA (light, moderate, and vigorous PA) across 3 domains (work, home, and leisure) at Wave 2. As described by Morin and Marsh,[27] FMMs reflect an extension of traditional latent profile analyses that relaxes the stringent and often-unrealistic assumption of conditional independence (ie, that there is no covariation between the indicator variables within each profile). Factor mixture models account for covariance between the indicator variables by estimating a higher-order, continuous, latent factor that is based on the profile indicator variables and specified to be invariant across profiles.[49]

Factor mixture model approaches also enable the estimation of latent profiles that better capture structural differences (shape effects) across different aspects of PA, which reflect the tendency for individuals to exhibit distinct patterns of vulnerability and strength in their combinations of light, moderate, and vigorous PA. This is achieved by incorporating the higher order, latent factor that captures level effects in overarching, global levels of PA, which refers to the tendency for some individuals to have low, medium, or high levels of light, moderate, and vigorous PA across all domains.[27] Factor mixture models were assessed with Mplus 8 using maximum likelihood robust estimation and the MplusAutomation package.[50,51] We estimated models with varying numbers of profiles, ranging from 2 through 6 profiles.[52]

Consistent with prior work using person-centered methods such as latent profile or class analysis,[37,53–55] age and other sociodemographic characteristics were not included as predictors or covariates in the Step 1 FMMs that identified the PA profiles. However, we did evaluate age differences in profile membership at baseline, controlled for age differences in our Step 2 autoregressive analyses that predicted longitudinal changes in cognition (as described below), and considered age as a moderator of the profile differences in cognitive aging in supplemental analyses (as described below).

Step 2 involved autoregressive analyses of covariance (ANCOVAs) procedures to test for profile differences in subsequent 2-wave, 9-year changes in 2 central indicators of cognitive functioning (episodic memory and executive functioning). ANCOVAs controlled for age, sex, race, education, income, self-reported physical health, and baseline levels of each outcome measure (ie, autoregressive effects). The outcome variables in our ANCOVA models thus reflected regressed change in cognitive functioning rather than raw change or gain scores, which can produce misleading results.[45–47] As recommended by Cohen et al[45] and Tennant et al[47] when using 2-wave longitudinal data, this autoregressive approach enabled us to examine whether PA profiles predicted changes in cognitive functioning while partialing out variance due to baseline differences in our cognitive outcome measures.[45,46] Omnibus ANCOVA effects were probed with *t*-test pairwise comparisons that contrasted covariate-adjusted trajectory means for each outcome measure.

We conducted several sensitivity analyses to evaluate the robustness of our main findings. Step 1 sensitivity analyses tested whether similar PA profiles were obtained when using the full sample with cross-sectional data at Wave 2 (cross-sectional $n = 4390$ vs longitudinal $n = 2688$). Step 2 sensitivity analyses tested the robustness of PA profile differences in cognitive aging by employing Mplus's BCH function to account for classification uncertainty and missing data using the full information maximum likelihood (FIML) method. Step 2 sensitivity analyses also tested whether PA profile differences in cognitive aging were consistent when controlling for retirement status (not retired $n = 2009$, retired $n = 673$; see the Supplementary Material for further detail on assessment of retirement status). Finally, supplemental autoregressive ordinary least squares (OLS) regression analyses tested demographic variables as moderator variables to assess the extent to which profile differences in trajectories of cognitive functioning depended on age, sex, race, education, or income.

Results

Demographic characteristics of the analyzed sample

At Wave 2 (baseline for the present study), the analyzed sample ($n = 2688$) had a mean age of 55 ± 11 years (range = 33-83), was 58% female and 89% White, had an average household income of $73 912, and 70% had some postsecondary education (see Table 1 for a summary of the sample characteristics).

Step 1: Latent profiles of PA

Results for our FMMs ($k = 2$-6 profile solutions) are shown in the Supplementary Material (Table S2). Model selection was guided by theory, interpretability, fit statistics, and profile size.[52,56–58] Several recommended fit indices were used[59] that included the Akaike information criterion (AIC), Bayesian information criterion (BIC), sample-size adjusted BIC (SABIC), the bootstrapped likelihood ratio test (BLRT), and the Lo-Mendell-Rubin (LMR) adjusted likelihood ratio test. We selected the 5-profile solution because it produced the best fit based on multiple criteria. Specifically, it had the largest marginal gain in fit across the AIC,

Table 1. Sample characteristics and descriptive statistics.[a]

Variable	*M* ± SD or *n* (%)	Range
Age[1]	54.96 ± 11.29	33-83
Sex[2]		
Male	1135 (42.4)	
Female	1544 (57.4)	
Race[2]		
White	2332 (89.0)	
Black	223 (8.5)	
Native American	7 (0.3)	
Asian or Pacific Islander	11 (0.4)	
Other	31 (1.2)	
Multiracial	17 (0.6)	
Education[1]	7.48 ± 2.53	1-12
Income[1]	73 912 ± 60 212	0-300 000
Health status[1]	3.67 ± 0.95	1-5
Light PA work[1]	3.65 ± 2.24	1-6
Light PA home[1]	5.19 ± 1.29	1-6
Light PA leisure[1]	5.09 ± 1.43	1-6
Moderate PA work[1]	2.52 ± 1.91	1-6
Moderate PA home[1]	3.89 ± 1.62	1-6
Moderate PA leisure[1]	4.09 ± 1.76	1-6
Vigorous PA work[1]	2.08 ± 1.67	1-6
Vigorous PA home[1]	3.15 ± 1.66	1-6
Vigorous PA leisure[1]	3.37 ± 1.86	1-6
Episodic memory[1]	0.09 ± 0.92	−2.50 to 3.64
Executive functioning[1]	0.09 ± 0.66	−2.58 to 2.34
Episodic memory[3]	−0.03 ± 1.00	−2.94 to 3.83
Executive functioning[3]	−0.17 ± 0.75	−5.63 to 2.02

Abbreviation: PA, physical activity.
[a]Frequency of PA at each intensity (light, moderate, vigorous) and within each domain (work, home, leisure) was self-reported and reverse coded as: 6 = several times a week, 5 = once a week, 4 = several times a month, 3 = once a month, 2 = less than once a month, 1 = never.
[1]Wave 1.
[2]Wave 2.
[3]Wave 3.

BIC, and SABIC indices; significant BLRT and LMR test statistics; no profiles with < 5% of the sample; and clear interpretability (see the Supplementary Material for further detail on model selection criteria and model comparisons).

The latent profiles that emerged in the 5-profile solution are depicted in Figure 1 and were labelled low PA ($n = 210$; 8%), low work PA ($n = 884$; 33%), average PA ($n = 334$; 12%), balanced PA ($n = 758$; 28%), and high PA ($n = 502$; 19%). The low PA profile had very low levels of PA across all domains. The low work PA profile had relatively average levels of light, moderate, and vigorous PA across domains, with the notable exception of very low PA across all intensity levels at work. The average PA profile reflected individuals with normative levels of light, moderate, and vigorous PA across domains. The balanced PA profile had very high levels of light PA combined with relatively average levels of moderate and vigorous PA. The high PA profile had high levels of light, moderate, and vigorous PA across domains.

Profile differences emerged for demographic characteristics that included age, sex, race, education, and income. All profiles varied in age and included participants from across the adult lifespan (ie, all profiles contained participants in their 30s, 40s, 50s, 60s, 70s, and 80s). However, the low PA and low work PA profiles were, on average, older in age than the other profiles (*M*s = 58-59 vs 51-53). Participants in the balanced PA and low work PA profiles were more likely to be female (63%-66% vs 44%-54%) and White (90%-93% vs 80%-85%) than participants in the other profiles. The low PA profile had lower levels of education (*M*s = 6.0 vs 7.0-8.0) and income (*M*s = $55 483 vs $71 894-$83 702) than the other profiles. We controlled for these sociodemographic characteristics in addition to physical health status in the subsequent analyses that tested for profile differences in cognitive functioning.

Step 2: Profile differences in 9-Year cognitive functioning

Separate ANCOVAs tested whether PA profiles differed in 9-year episodic memory and executive functioning. ANCOVAs controlled for age, sex, race, education, income, self-reported physical health, and baseline levels of each outcome measure (ie, autoregressive effects). Results indicated that there was an omnibus profile effect for executive functioning, $F_{4,2288} = 3.21$, $P = .012$, but not for episodic memory, $F_{4,2528} = 0.326$, $P = .860$. The significant omnibus effect indicated that the 5 PA profiles differed in their longitudinal executive functioning. Pairwise comparisons that probed this omnibus effect showed the balanced PA profile experienced less decline in 9-year executive functioning relative to the low PA profile ($M_{diff} = .09$, SE = .041, $t_{2288} = 2.07$, $P = .037$, Cohen's $d = 0.12$) and the low work PA profile ($M_{diff} = .08$, SE = .024, $t_{2288} = 3.21$, $P = .001$, Cohen's $d = 0.10$). The high PA profile also experienced less decline in executive functioning relative to the low work PA profile ($M_{diff} = .06$, SE = .028, $t_{2288} = 2.25$, $P = .026$, Cohen's $d = 0.09$), but did not differ from the balanced PA profile ($P = .633$).

To contextualize the practical significance and effect sizes of the profile differences, we generated predicted values that

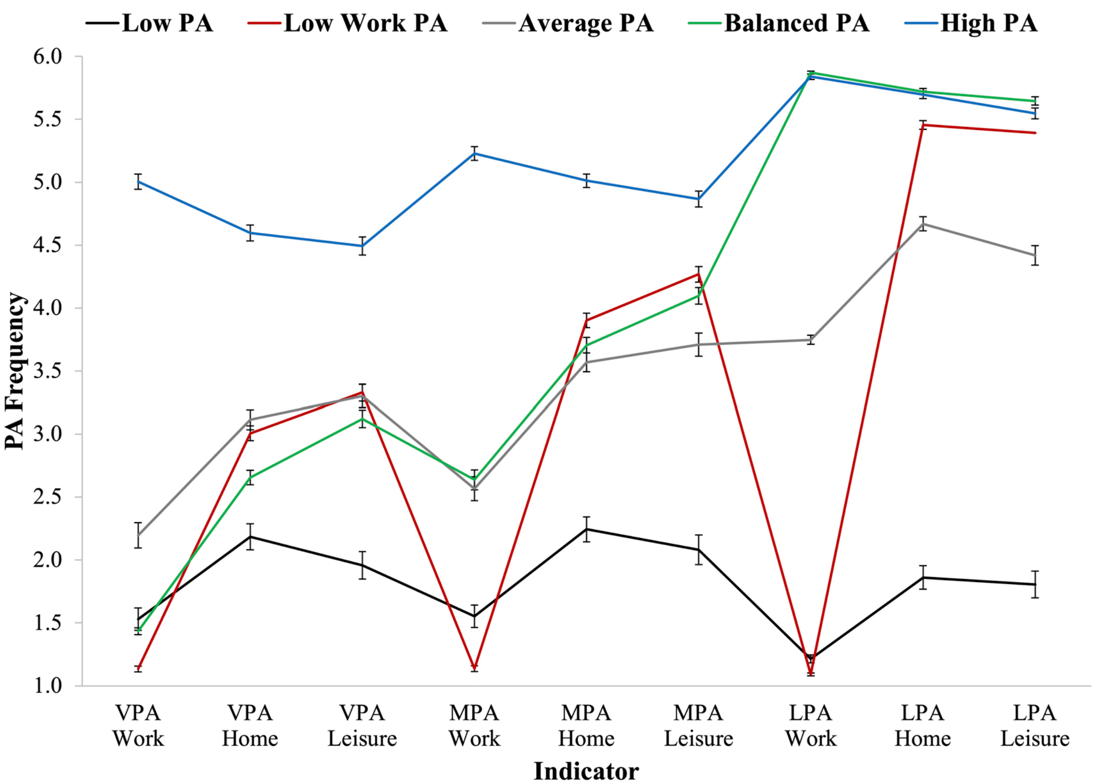

Figure 1. Latent profiles of physical activity (PA) across intensities and domains from the $k = 5$ factor mixture model. VPA, vigorous physical activity; MPA, moderate physical activity; LPA, light physical activity. Low PA $n = 210$. Low work PA $n = 884$. Average PA $n = 334$. Balanced PA $n = 758$. High PA $n = 502$. Frequency of PA at each intensity (light, moderate, vigorous) and within each domain (work, home, leisure) was self-reported and reverse coded as: 6 = several times a week, 5 = once a week, 4 = several times a month, 3 = once a month, 2 = less than once a month, 1 = never.

adjusted for raw, average sample declines of −.257 units in executive functioning over the 9-year follow-up (Figure 2). Small but meaningful differences emerged in predicted executive functioning scores for those in the balanced PA profile (−.219) relative to those in the low PA (−.304) and low work PA profiles (−.296). These estimates suggest that rates of 9-year decline in executive functioning were reduced by more than 25% (−.219 vs −.304, −.296) for individuals in the balanced PA profile. Rates of decline were also reduced by 21% for those in the high PA profile relative to the low work PA profile (−.233 vs −.296).

We also employed a supplemental classification approach to further contextualize the practical significance of our findings. Following Cotter and Lachman,[35] we classified profiles into PA categories that approximated those employed by the CDC (inactive, not regularly active, regularly active). Specifically, we classified each profile based on whether it exhibited low (inactive), moderate (not regularly active), and high (regularly active) levels of light, moderate, and/or vigorous PA on average across domains. Profiles were classified as low (inactive) in light PA if their average light PA score across domains was < 4 (ie, engaged in light PA never, less than once a month, or once a month). Profiles were classified as moderate in light PA (not regularly active) if their average light PA score across domains was 4-5 (ie, engaged in light PA once a week or several times a month). Profiles were classified as high in light PA (regularly active) if their average light PA score across domains was > 5 (ie, engaged in light PA several times a week). This classification process was then repeated for moderate and vigorous PA.

Results indicated that the low PA, low work PA, and average PA profiles were all classified as having low levels (inactive) of light PA, moderate PA, and vigorous PA, with the sole exception that the average PA profile had moderate levels (not regularly active) of light PA. The balanced PA profile was classified as having low levels (inactive) of moderate and vigorous PA, but high levels (regularly active) of light PA. The high PA profile was classified as having high levels (regularly active) of light PA and moderate PA, but moderate levels (not regularly active) of vigorous PA. Thus, only the balanced PA and high PA profiles were classified as being regularly active in their light PA, with the high PA profile also meeting the regular activity threshold for moderate PA. This supplemental classification approach suggests that, at a minimum, high levels of light PA that involve engaging in light PA several times a week may be necessary to help buffer against age-related cognitive declines.

Sensitivity analyses

Profiles in cross-sectional sample

Our main Step 1 models were based on participants with longitudinal data at Waves 2 and 3 because a primary aim was to test for profile differences in 9-year trajectories of cognitive functioning. Sensitivity analyses evaluated the robustness of the observed latent profiles using the full sample that had cross-sectional data at Wave 2 ($n = 4390$). Results were consistent with the main analyses such that the 5-profile model exhibited the best fit, and the same 5 profiles emerged (Figure S1).

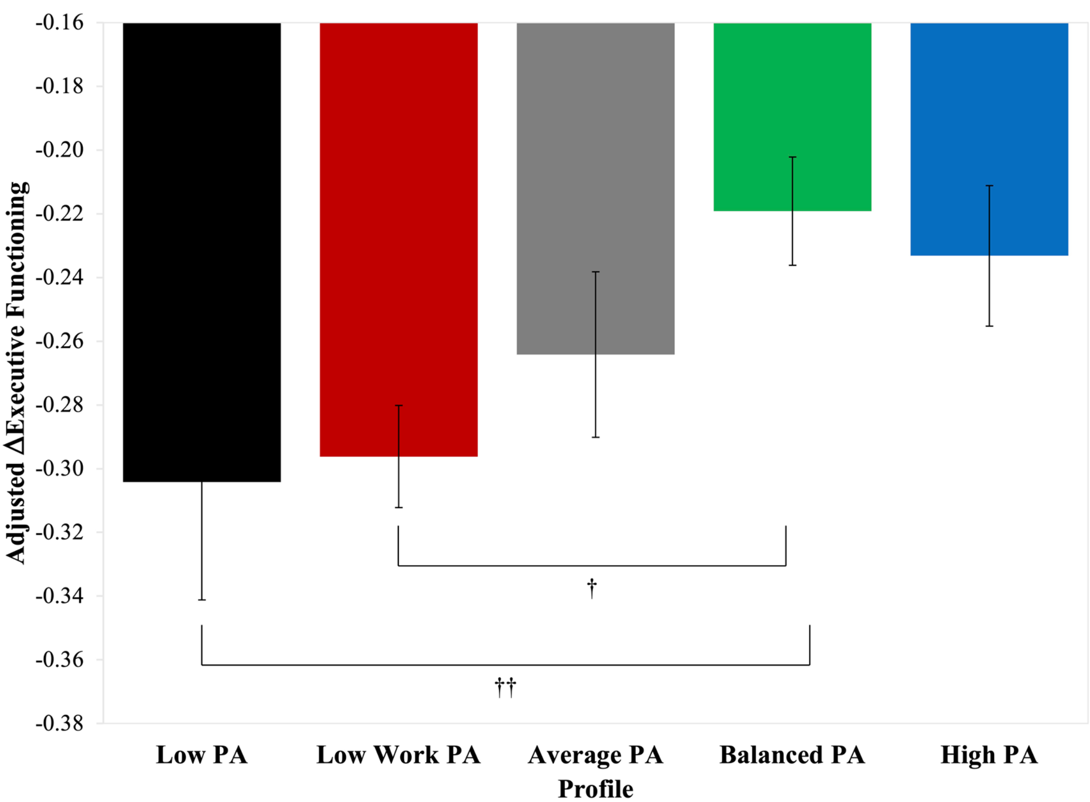

Figure 2. Contextualized effect sizes of profile differences on regressed 9-year change in executive functioning. Estimates suggested rates of 9-year decline in executive functioning were, respectively, reduced by approximately 26% and 28% for the balanced physical activity (PA) profile versus the low PA and low work PA profiles. Predicted values were adjusted for model covariates and for (raw) average sample declines of −.257 units in executive functioning. †26% reduction in rate of decline. ††28% reduction in rate of decline.

Profile differences employing BCH

Step 2 sensitivity analyses used Mplus's Auxiliary BCH function to estimate profile differences in regressed change in executive functioning while accounting for classification uncertainty and missing data using FIML.[52,54] Results were consistent with the 2-step process employed in the main analyses. BCH contrasts showed the balanced PA profile had less decline in executive functioning relative to the low PA profile (M_{diff} = .09, χ^2 = 4.42, P = .036) and the low work PA profile (M_{diff} = .08, χ^2 = 9.63, P = .002). The high PA profile also experienced less decline in executive functioning relative to the low work PA profile (M_{diff} = .06, χ^2 = 4.51, P = .034), but did not differ from the balanced PA profile (P = .534).

Retirement status covariate

Sensitivity analyses tested the robustness of the Step 2 profile differences when including retirement status as an additional covariate (not retired n = 2009, retired n = 673). Results largely replicated the main findings: Although the high PA profile no longer exhibited less decline in executive functioning than the low work PA profile (P = .150), the balanced PA profile still declined marginally less than the low PA profile (P = .058) and less than the low work PA profile (P = .020).

Sociodemographic differences

Supplemental autoregressive OLS regression models tested whether Step 2 profile differences were moderated by sociodemographic characteristics that included age, sex, race, education, and income. Analyses were conducted using dummy-coded profile variables (reference group = balanced PA). Results yielded no significant interaction effects between the profiles and age (Ps > .200) or the other sociodemographic characteristics (Ps = .054-.939). The only exception was a Sex × Low PA interaction (b = .23, P = .004) that suggested low PA (vs balanced PA) may potentially be less detrimental for women's longitudinal executive functioning than men's. Collectively these supplemental analyses indicated that profile differences did not systematically differ across age, sex, education, income, or health status.

Discussion

We sought to shed light on how light, moderate, and vigorous PA combine to buffer against cognitive declines in midlife and old age. Results advance the literature in identifying multidimensional combinations (profiles) of PA and by showing that certain profiles characterized by balanced levels of PA across life domains protected against losses in 9-year executive functioning. Findings from the supplemental moderation analyses also suggest that the cognitive health benefits of balanced PA were largely consistent across the adult lifespan, for men and women, across the socioeconomic status (SES) spectrum, and for those with better or worse health status.

Our study is the first to adopt a person-centered approach to identify meaningful profiles of PA across intensity levels and life domains. In contrast to variable-centered methods,[4,16–18] this approach may better reflect ecological realities of human PA wherein people typically engage in multiple forms of PA during their day-to-day lives. Our findings suggest that light, moderate, and vigorous PA operate in tandem across domains and can be captured by complex rather than main effect combinations. In other words, the present results contribute to a more nuanced understanding of PA in providing initial evidence that light, moderate, and vigorous PA co-occur in meaningful mixtures or combinations rather than in isolation.

The most common profiles in our sample were characterized by low work PA (33%) or balanced PA (28%). These profiles offer an interesting contrast in understanding potential compensatory effects of PA at certain intensities and in select domains. Individuals in these profiles were relatively similar in their levels of PA across intensities and domains with a notable exception: The low work PA profile exhibited substantially lower levels of light, moderate, and vigorous PA in the domain of work. Results of the profile contrasts suggest that this difference had small but practically significant consequences for healthy cognitive aging: Contextualized effect sizes suggested that rates of 9-year decline in executive functioning for the balanced PA profile were reduced by more than 25% relative to those in the low work PA profile.

These findings suggest that average-to-high levels of light, moderate, and vigorous PA in the domains of home and leisure may not sufficiently compensate for very low levels of work PA. In other words, at least modest levels of PA across life domains (and intensity levels) may be needed to promote healthy cognitive aging. However, our results also point to some potential compensatory benefits of maintaining high levels of light PA. Specifically, the balanced PA profile had average levels of moderate PA and below average levels of vigorous PA across domains. They compensated for these relatively modest levels of moderate-to-vigorous PA with the highest levels of light PA across domains. Findings suggested that this compensatory approach was effective in supporting cognitive functioning over the 9-year follow-up. Particularly noteworthy was that the balanced PA profile experienced the least decline in 9-year executive functioning. In fact, they experienced slightly (although not significantly) less decline than their peers in the high PA profile who had very high levels of light, moderate, and vigorous PA across all domains.

Although further research is needed to replicate and extend our findings, the present results have the potential to inform public health messaging and the development of multidimensional interventions that target light, moderate, and vigorous PA to promote health. For example, the Physical Activity Guidelines for Americans only provides recommendations for moderate and vigorous intensity aerobic PA,[60] but nearly half of US adults are not meeting any PA recommendation.[61] A large proportion of US adults alternatively engage in light PA, and participation in light PA is associated with reduced risk of cardiometabolic disease, cognitive impairment, and early mortality.[19,62] The present findings suggest that public health messaging could be modified to focus on maintaining at least modest levels of moderate-to-vigorous PA while emphasizing the importance of engaging in high levels of more feasible light PAs that remain readily achievable across the adult lifespan. This messaging would be consistent with our supplemental classification approach that suggested, at a minimum, middle-aged and older adults could be encouraged to maintain high levels of light PA (engaging in light PA several times a week) to help preserve cognitive health as they age. Our findings also have implications for evidence-based interventions considering that light, moderate, and vigorous PA exhibit change over time, are modifiable, and may represent viable target treatment mechanisms.[7,29,63,64] Research is needed to examine whether well-timed interventions designed to buffer against losses in vigorous, moderate, and especially light PA can improve cognitive aging outcomes when administered prior to or shortly after the onset of age-related health constraints.[65]

Although our study is supported by a prospective design and 9-year cognitive functioning data in a large national sample, it is not without limitations. First, as is typical in large-scale, longitudinal field studies,[66,67] MIDUS measures of PA were based on self-reports. Individuals tend to overestimate their PA which can result in some bias.[68] Future research is needed using objectively assessed PA. Although we employed a prospective design and controlled for an array of sociodemographic and health-related factors implicated in cognitive aging, we cannot rule out the possibility that unmeasured or uncontrolled "third variables" could account for the observed relationships. Randomized controlled trials to increase combinations of light, moderate, and vigorous PA are needed to establish that multidimensional increases in PA precipitate subsequent changes in cognition. Third, although we included the Milwaukee oversample of Black participants, the MIDUS sample was largely White and upper-middle class. Further research is needed to replicate these findings in samples that are more racially and socioeconomically diverse. Fourth, MIDUS did not collect data on sedentary behavior. Future studies should extend the present research by examining how sedentary behavior may be reflected in the present profiles to better capture common patterns of PA-related health behaviors.

In sum, the present findings provide evidence that light, moderate, and vigorous PA in multiple life domains combine to form meaningful profiles that have consequences for healthy cognitive aging. Participants in our national sample who balanced their PA across intensity levels and life domains experienced the least decline in their executive functioning over a 9-year follow-up. Findings also suggest that the cognitive health benefits of balanced PA were consistent across the adult lifespan, for men and women, across the socioeconomic spectrum, and for those in better or worse health status. Healthcare providers should recommend maintaining high levels of light PA that are supplemented with at least modest amounts of moderate and vigorous PA to their patients as a feasible mode for engaging in PA that may also preserve cognitive function.

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Author contributions

Jeremy M. Hamm (Conceptualization [lead], Formal analysis [lead], Funding acquisition [lead], Methodology [lead], Writing—original draft [lead], Writing—review & editing [lead]), Margie E. Lachman (Formal analysis [supporting], Funding acquisition [supporting], Writing—review & editing [supporting]), Ryan McGrath (Formal analysis [supporting], Writing—review & editing [supporting]), Katherine A. Duggan (Formal analysis [supporting], Funding acquisition [supporting], Writing—review & editing [supporting]), and Kelly Parker (Formal analysis [supporting], Writing—review & editing [supporting])

Supplementary material

Supplementary material is available at *Annals of Behavioral Medicine* online.

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Conflicts of interest

None declared.

Data availability

Deidentified MIDUS data are available in a protected archive from the Inter-university Consortium for Political and Social Research after registration: https://www.icpsr.umich.edu/icpsrweb/ICPSR/series/203.

Study registration

This study was not formally registered.

Analytic plan pre-registration

The analysis plan was not formally pre-registered.

Analytic code availability

Analytic code used to conduct the analyses presented in this study are not available in a public archive. They may be available by emailing the corresponding author.

Materials availability

All MIDUS study materials are available in a public archive from the Inter-university Consortium for Political and Social Research after registration: https://www.icpsr.umich.edu/icpsrweb/ICPSR/series/203.

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