Physical activity/fitness peaks during perimenopause and BMI change patterns are not associated with baseline activity/fitness in women: a longitudinal study with a median 7-year follow-up

Xuemei Sui,[1] Jiajia Zhang,[2] Duck-chul Lee,[1] Timothy S Church,[3] Wenbin Lu,[4] Junxiu Liu,[2] Steven N Blair[1,2]

[1]Department of Exercise Science, University of South Carolina, Arnold School of Public Health, Columbia, South Carolina, USA
[2]Department of Epidemiology and Biostatistics, University of South Carolina, Arnold School of Public Health, Columbia, South Carolina, USA
[3]Pennington Biomedical Research Center, Preventive Medicine, Baton Rouge, Louisiana, USA
[4]Department of Statistics, North Carolina State University, Raleigh, North Carolina, USA

Correspondence to
Dr Xuemei Sui, Department of Exercise Science, University of South Carolina, Arnold School of Public Health, 921 Assembly Street, Columbia, SC 29208, USA; msui@mailbox.sc.edu

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ABSTRACT

Objective To assess the age-associated longitudinal trends in cardiorespiratory fitness (CRF), leisure-time physical activity (PA), and body mass index (BMI) across the lifespan in a cohort of adult women.

Methods The sample included 1467 women from the Aerobics Center Longitudinal Study who were 30–79 years old at baseline and had 3–22 health examinations between 1971 and 2006. CRF was quantified by maximal Balke treadmill exercise tests. The total metabolic equivalent-minutes/week of self-reported PA and measured BMI (kg/m^2) were calculated.

Results The overall pattern of CRF decreased over time. After age 60 years, fitness level tended to decline rapidly. Women at age 50 had the highest PA level, which decreased after age 50 and plateaued at age 60. The overall pattern of BMI increased with age. However, after age 60 years the rate of increase in BMI became much slower. Adjusting for smoking, health status, and the individual exposures of CRF, PA and BMI did not influence the observed associations. Women who did not meet current PA recommendation or those who were low fit at baseline had a higher BMI throughout adulthood than their more active or fit peers, but the trajectory of BMI was unassociated with baseline activity or fitness levels.

Conclusion We concluded that the age-related longitudinal patterns in physical activity and fitness are not linear. Baseline activity and fitness levels are associated with BMI status during adulthood, but do not affect BMI change trajectory.

Although there is typically an upward trajectory of body weight over the adult years, there also are other patterns of weight change over time.[1–3] For physical activity (PA) and cardiorespiratory fitness (CRF), the general trajectory shows a decline with increasing age.[4–7] Previous studies on age-associated change in body weight, activity and fitness were often based on cross-sectional data.[1 8 9] Longitudinal studies often used models assuming a parametric regression approach, which ignored other non-parametric patterns of age-associated trajectories of these exposures.[5 6 10] No studies simultaneously described age-associated regression curves for body weight, PA and CRF across the adult lifespan in a well-defined population-based sample of women. Defining age-related activity, fitness and body weight trajectories is an important public health goal, because these factors are key risk factors contributing to the development of cardiovascular disease and other health problems.[11]

Moderate and higher levels of PA and CRF attenuate the adverse health effects of overweight or obesity.[12 13] Previous longitudinal studies have shown an inverse association between self-reported PA and body weight;[14–19] however, a majority of these studies included only two measurements of self-reported PA and body weight,[14–18] and primarily involved middle-aged men.[14–17] Whereas most studies have been based on self-reported PA, self-reported measures only modestly correlate with objective measures obtained using criterion methods.[20 21] To overcome the shortcomings of existing literature, studies are needed that examine not only self-reported PA but also objective exposures such as CRF,[21 22] a reproducible measure that reflects recent PA habits, disease and genetics.[23] Although the literature is limited, longitudinal changes in fitness have been associated with reciprocal changes in body weight in one study[24] and parallel changes in another study.[25]

The aim of this study was to model the serial data from women enrolled in the Aerobics Center Longitudinal Study (ACLS) to: (i) define the longitudinal, ageing trajectory of self-reported PA, objectively-measured CRF and body mass index (BMI); (ii) determine if baseline activity or fitness level alters the BMI-age trajectory across adult lifespan; and (iii) provide a practical introduction to generalised additive mixed models (GAMM) for the analysis of longitudinal health data (here BMI, PA and CRF), because GAMM can combine the ability to estimate a smooth time trend and random effects and control for known important fixed covariates, facilitating detection of age-associated exposure patterns throughout the lifespan.

METHODS

Study population

The ACLS is a prospective observational study composed of participants who received preventive medical examinations at the Cooper Clinic in Dallas, Texas. It is an open cohort study; individuals of all ages received follow-up examinations throughout the study period. The current analysis included 1467 women ranging in baseline age from 30 to 79 years who completed at least three clinical examinations, including fitness testing, between 1971 and 2006. Those who were unable to complete an exercise stress test to at least 85% of their age-predicted maximal heart rate (220 minus age in years) were excluded. All participants were free of cancer, heart attack, stroke and diabetes at any clinical examination. Most participants were white (>95%), well educated and of middle-to-high socio-economic status. This study was reviewed and approved annually by the Cooper Institute Institutional Review Board.

Clinical examination

Participants provided written informed consent to participate in the examination and follow-up study. All medical evaluations included personal and family histories, a questionnaire on demographic characteristics and health habits, a physical examination, anthropometry, electrocardiogram, blood chemistry analyses, blood pressure measurements and a maximal exercise test on a treadmill. The comprehensive medical evaluation has been described in detail elsewhere.[6 26] Briefly, body mass index (BMI) was calculated as measured weight in kilograms divided by height in square metres. Normal weight (BMI<25), overweight (25≤BMI<30) and obese (BMI≥30) were defined. Smoking habits were obtained from a standardised questionnaire, and participants were classified as non-smokers or current smokers at the time of each examination.

Leisure-time PA was assessed on the medical history questionnaire by self-reported leisure-time or recreational activities during the past 3 months. The questionnaire has been validated previously.[27 28] We created PA categories based on responses to 10 specific activities: walking, jogging, running, treadmill exercise, cycling, stationary cycling, swimming, racquet sports, aerobic dance and other sports-related activities (eg, basketball or soccer). If participants indicated that they were participating in activities, they answered additional questions about the frequency (number of workouts per week) and duration (minutes of workouts per session) of those activities. For walking, jogging, running, treadmill exercise and cycling, they also were asked to report speed (eg, average time per mile). The intensities of activities were estimated via speed-specific or activity-specific metabolic equivalent (MET) values from the Compendium of Physical Activities.[29] To calculate the total volume of PA, the MET value for a given speed or activity was multiplied by the frequency and the duration and then summed over all activities, resulting in total MET-minutes per week of PA, which is the principal metric used in the 2008 PA Guidelines Advisory Committee Report.[30] All participants were also classified into two PA categories based on the PA Guidelines Advisory Committee Report: 'not meeting the recommended amount of PA (<500 MET-minutes/week)', and 'meeting the recommended amount of PA (≥500 MET-minutes/week)'. For an individual to meet the recommended PA level, she can do at least 150 min of moderate-intensity activity (such as brisk walking) or 75 min of vigorous-intensity activity (such as jogging) per week.

We determined CRF using a modified Balke maximal exercise test, as described in previous publications.[26 31] The treadmill speed was 88 m/min for the first 25 min. During this time, the grade was 0% for the first minute, 2% the second minute and increased 1% each minute until 25 min had elapsed. After 25 min, the grade remained constant while the speed increased 5.4 m/min each minute until test termination. Participants were encouraged to give a maximal effort during the test. The mean (SD) percentage of age-predicted maximal heart rate achieved during exercise was 101.5 (6.6). The previously validated regression formula ((1.44×exercise duration in minutes)+14.99)/3.5 was used to convert maximal treadmill time to METs.[32] One MET corresponds to an oxygen uptake of 3.5 ml/kg/min, the energy expenditure at a resting state. Total time of the test correlates highly (r=0.94) with measured maximal oxygen uptake.[33] Thus, treadmill time expressed in METs is analogous to maximal aerobic power (peak VO_2) and is used as an objective laboratory measure of CRF. We also assigned women to age-specific fitness categories based on their total time on the treadmill test. We classified the lowest 20% of the fitness distribution as low fit, the next 40% as moderately fit and the upper 40% as high fit, as in our previous reports, which were based on data from the entire cohort. The detailed cutpoints of treadmill duration and corresponding METs values have been reported previously.[34]

Statistical analysis

Generalised additive mixed model (GAMM) was used to analyse the longitudinal data.[35] GAMM is the generalisation of the general linear mixed regression model that can model both linear and non-linear predictors. Note that linear predictor is a special case of nonlinear predictor. One of the appealing properties of GAMM is that it can include nonlinear predictors in the model without specific assumptions on their patterns and can estimate the non-linear predictor by the spline technique,[36 37] which greatly improves the model's flexibility. The dependent variables for the three GAMM analyses were BMI, PA (MET—mintues/week) and CRF (METs), respectively. The predictors were age (years), smoking status (current smoker or not) and two of the three dependent variables. The random effects were used to account for the longitudinal change in each participant. The estimated smooth curves of age were used to reveal the nonlinear relationship between age and the dependent variables. The unadjusted model examined the longitudinal change in each of the dependent variables due to ageing, while the adjusted model revealed the longitudinal change in each of the dependent variables due to ageing by adjusting for smoking status and the other two dependent variables linearly. Finally, we examined the age-associated BMI change across baseline PA (meeting the recommended PA and not) and CRF (low, moderate and high) after adjusting for smoking status and CRF or PA, respectively. All p values were two-tailed, and values of <0.05 were considered to indicate statistical significance. Analyses were done using R software, V.11.1. Specifically, the 'gamm' function was applied to the GAMM. The detailed R code regarding how to implement GAMM and how to specify the random correlation structure in the present study is available on request from the corresponding author.

RESULTS

Characteristics of women according to age groups

Table 1 provides the characteristics of women from all the follow-up examinations by age group. Ages ranged from 30 to 79 years, and the mean (SD) of age at baseline was 44.8 (8.5) years. The total number of exams completed was 7041. The number of exams completed by each woman ranged from 3 to 22 (mean: 5 and median: 4). The median (IQR) length of follow-up was 6.6 (8.1) years. The treadmill time was shorter and the prevalence of smoking was lower in the older groups. About17.3% of women exceeded a BMI of 25. Approximately half reported that they met the recommended levels of PA (≥500 MET-minutes/week).

Unadjusted and adjusted parameter estimates for PA, CRF and BMI

Table 2 presents results from the unadjusted and adjusted GAMM for PA, CRF and BMI. The relation between age and unadjusted PA, CRF and BMI was nonlinear for all variables

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Table 1 Descriptive statistics for all observations of women according to age group

Variable	All observations	Observations by age group (year)				
		30–40	40–49	50–59	60–69	≥70
No. of observations	7041	1015	2532	2370	996	128
Age (mean±SD, year)	49.8±9.2	36.1±2.5	44.8±2.9	54.1±2.8	63.3±2.7	72.2±2.0
Height (mean±SD, cm)	164.3±5.9	165.2±5.8	164.5±6.0	164.1±5.8	163.6±5.7	160.6±6.3
Weight (mean±SD, kg)	61.1±9.2	59.3±9.1	61.0±9.8	61.7±8.8	62.0±8.8	58.8±7.9
BMI (mean±SD, kg/m^2)	22.6±3.2	21.7±3.0	22.5±3.2	22.9±3.1	23.1±3.1	22.8±2.9
Leisure-time PA in MET-minutes per week (median, IQR)	513, 1170	357, 1013	537, 1237	570, 1230	513, 1085	456, 1034
Not meeting the recommendation (%)	49.0	55.8	48.2	46.6	49.1	53.9
CRF (mean±SD, METs)	10.1±2.0	11.1±2.0	10.6±1.9	9.8±1.8	8.9±1.6	8.2±1.4
Low (%)	3.3	5.0	4.2	2.4	1.7	0.8
Moderate (%)	20.6	30.2	22.8	16.0	14.1	34.4
High (%)	76.2	64.8	73.1	81.6	84.2	64.8
Current smoker (%)	5.1	8.8	5.9	3.6	3.3	2.3

BMI, body mass index; CRF, cardiorespiratory fitness; IQR, IQ range; MET, Metabolic equivalent; PA, physical activity.

since all the unadjusted smooth terms (spline (age)) were significant (all, $p<0.0001$). There was a steep decline in CRF after age 45 years, and this decline accelerated after 60 years of age (figure 1, top panel). The middle panel of figure 1 shows that women at age 50 had the highest PA levels. The bottom panel of figure 1 shows that the overall pattern of BMI was upward. After 60 years of age, the rate of increase in BMI became much slower. Adjusting for smoking and the individual exposure of CRF, PA and BMI did not significantly influence the observed associations (table 2). The large CIs in the later years for PA and BMI were due to the small numbers of women in the older age groups.

Changes in BMI with baseline PA and fitness

Finally, we examined BMI changes with age across baseline PA (meeting the recommended level of PA and not meeting the recommended level of PA, figure 2A) and CRF (low, moderate and high, figure 2B) groups. The figure shows the longitudinal change in BMI from 30 to 80 years of age for a non-smoker. Women who did not meet the PA recommendation at baseline had a higher BMI throughout adulthood compared with those who met the recommendation at baseline, after adjusting for smoking status and CRF. Women who were fit at baseline had a lower BMI throughout adulthood compared with their unfit peers, after adjusting for smoking status and PA. No significant interaction was observed between BMI and PA or CRF. However, the age-associated BMI trajectory across the entire follow-up did not differ based on baseline activity or fitness levels.

DISCUSSION

Key study findings

The purpose of this study was to assess the longitudinal patterns of PA, CRF and BMI with ageing in a cohort of healthy women across the adult lifespan using GAMM. The nature of the associations between age and PA, CRF and BMI differed. There was a positive curvilinear association between BMI and age, after controlling for smoking, and each of the other dependent variables. However, the trend of self-reported PA and CRF with ageing initially increased and ultimately decreased at 50 and 45 years old, respectively. The finding that the decline in activity and fitness begins in the perimenopause identifies a critical time window for physical activity promotion in women. In addition, the positive age-associated BMI change was observed in initially active or high fit women as well as those who were less active or low fit at baseline.

Comparison with previous literature on age-associated activity and fitness change

Previous cross-sectional studies have shown an overall trend of small declines in the proportion of the population engaged in recommended levels of activity.[8 9] In addition, declines in physical activity levels are prominent during young adulthood, and then taper off during middle and older adult life.[8] These data have been useful in understanding population trends in physical activity, and in establishing recommendations to improve physical activity levels as part of the national public health agenda.[9 38] The present study provides novel data describing the longitudinal patterns of physical activity and fitness during adulthood in a well-defined sample with serial measures of habitual physical activity and maximal treadmill exercise tests. Very few studies have the data to examine both physical activity and fitness across the lifespan. Jackson *et al*[25] examined changes in self-reported physical activity levels and maximal treadmill exercise duration in a cohort of men aged 17–71 years at baseline for whom an additional measurement on activity and fitness was available at an average of 8 years later. The percentage of men reporting no leisure-time activity declined from 31.5% to 20.5%, and maximal treadmill duration increased from 18.9 to 19.5 min (3.2% increase) between the two examinations. Recently, longitudinal studies with more than two measures of exposure show an accelerated decline in CRF with ageing in both men and women.[5 6] However, these studies required forcing the data into a predefined model. The current analysis applied GAMM modelling techniques, which fit both linear and non-linear patterns of predictors. We found that CRF increased with age and then decreased at a non-linear rate after ages 42–45 years. The decline in CRF after ages 42–45 years was consistent with previous reports,[5 6] but the slight increase before the age of 40 years in women was a unique finding of our analyses, and therefore should be confirmed in future studies. One explanation for the difference might be the modelling technique we chose, because the GAMM can follow the data instead of forcing the data with certain assumptions.

The ageing pattern of self-reported PA was similar to the fitness pattern, with a slightly delayed decline around age 50. A recent paper from Brown *et al* suggested significant

Table 2 Unadjusted and adjusted parameter estimates of BMI, PA and CRF

	Unadjusted estimates (SE)	Adjusted estimates (SE)	Adjusted p value
BMI (kg/m^2)*			
Fixed part			
Linear part			
Intercept	22.85 (0.08)	22.62 (0.08)	<0.0001
Current smoker	–	−0.23 (0.10)	0.02
Not meeting the recommended PA (<500 MET-minutes/week)	–	0.11 (0.04)	0.002
Low fit		2.01 (0.11)	<0.0001
Moderate fit	–	0.57 (0.17)	<0.0001
Nonlinear part			
Smooth age	DF=2.87 (p<0.0001)	DF=4.21	<0.001
Random part			
SD intercept	3.00	2.91	
SD error	1.15	1.11	
PA, MET-minutes/week†			
Fixed part			
Linear part			
Intercept	810.97 (20.22)	965.74 (21.72)	<0.0001
Current smoke	–	−190.44 (66.22)	0.004
Overweight (25≤BMI<30)	–	−112.073 (42.61)	0.008
Obese (BMI≥30)		−66.59 (91.87)	0.47
Low fit		−725.76 (76.36)	<0.0001
Moderate fit	–	−472.34 (34.38)	<0.0001
Nonlinear part			
Smooth age	DF=2.88 (p<0.0001)	DF=2.39	0.06
Random part			
SD intercept	624.52	561.31	
SD error	928.91	924.34	
CRF, METs‡			
Fixed part			
Linear part			
Intercept	10.08 (0.04)	10.54 (0.04)	<0.0001
Current smoker	–	−0.21 (0.07)	0.004
Overweight (25≤BMI<30)		−0.64 (0.05)	<0.0001
Obese (BMI≥30)	–	−1.60 (0.11)	<0.0001
Not meeting the recommended PA (<500 MET-minutes/week)	–	−0.59 (0.026)	<0.0001
Nonlinear part			
Smooth age	df=6.03 (p<0.0001)	df=6.21	<0.0001
Random part			
SD intercept	1.63	1.46	
SD error	0.87	0.83	

BMI, body mass index; CRF, cardiorespiratory fitness; MET, Metabolic equivalent; PA, physical activity.
Notes: The 'nonlinear part' lists the degree of freedom of the fitted nonlinear curve. The p value <0.05 means the fitted nonlinear relationship between age and dependent variable is significant. The 'random part' is used to describe the variation of the random effects in the longitudinal pattern. The small variation in our Table indicates that the variation among participants is small in the Aerobics Center Longitudinal Study.
*Adjusted for smoking (current smoker or not), PA (meet the recommended level or not) and CRF (low, moderate or high).
†Adjusted for smoking (current smoker or not), BMI (normal weight, overweight or obese) and CRF (low, moderate or high).
‡Adjusted for smoking (current smoker or not), BMI (normal weight, overweight or obese) and PA (meeting the recommended level or not).

associations between age-specific life events and PA changes.[39] Birth of a grandchild, going through menopause and illness or death of a close family member were associated with increased odds of decreasing PA in 8762 mid-age women. Our finding of a decline in PA around age 50 partly supported her hypothesis. Accurate measurement of true daily physical activity is more challenging than measuring CRF, and information on PA from other domains, such as occupation, home or active commuting, was not available in this study. An accurate measure of total physical activity might have revealed a similar ageing trend. Therefore, future studies need to incorporate other domains of physical activity and selected life events, as well as include an objective measure of physical activity, in order to provide a clear picture of the ageing-related physical activity pattern.

Comparison with previous literature on age-associated BMI change

Changes in body weight during adulthood occur at varying ages and in different degrees of magnitude. Cross-sectional data suggest that adults experience a weight gain between about 30 and 50 years of age, with a short plateau to about age 60 years, and then lose modest amounts through their 80s.[1] Cross-sectional data from the National Health and Nutrition Examination Survey (NHANES) suggest two body composition

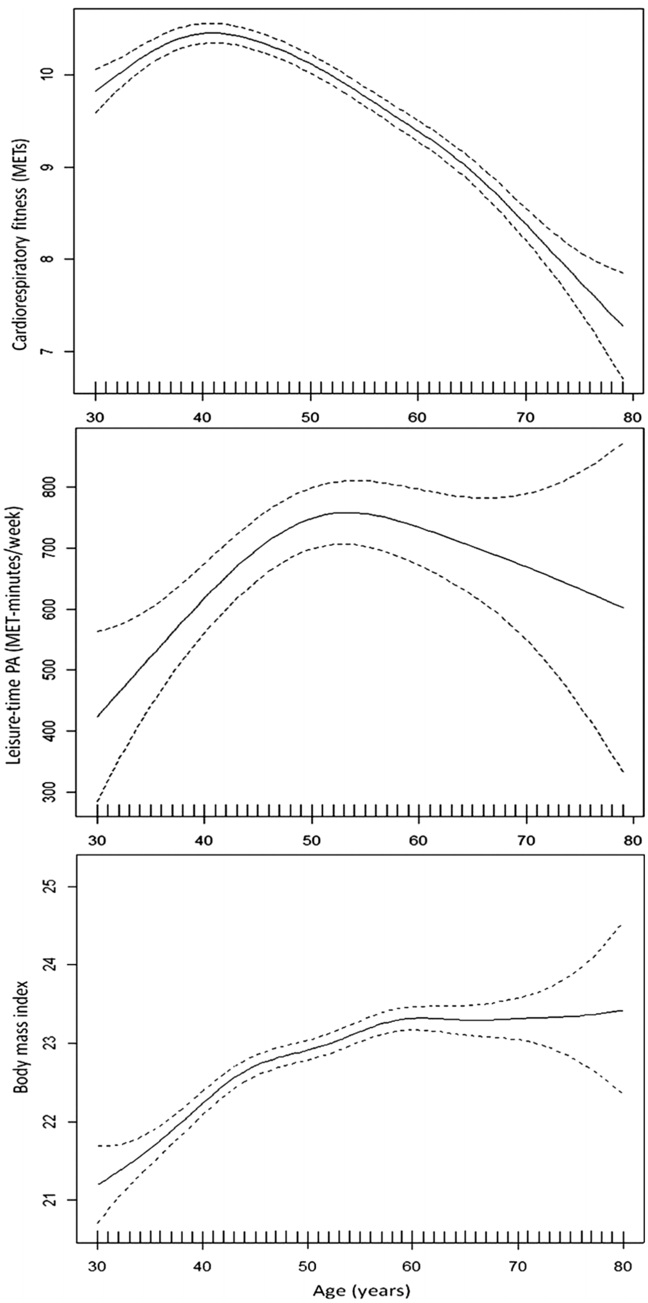

Figure 1 Age-associated cardiorespiratory fitness (top panel), leisure-time physical activity (middle panel) and body mass index (BMI, bottom panel) change in women assuming that they did not smoke, were normal weight (when fitness and physical activity are the dependent variables), met the recommended level of physical activity (when fitness as dependent variable), and were at least moderate fit (when BMI is the dependent variable), Aerobics Center Longitudinal Study, Dallas, Texas, 1971–2006.

trends using BMI as a measure of obesity. First, a secular trend, the prevalence of obesity among American adults, systematically increased over the past 30 years.[3 40 41] Second, the prevalence of obesity increases with ageing.[2 3] Our longitudinal results provide strong evidence that changes in BMI associated with ageing were upward but curvilinear. BMI increased at a higher rate before the age of 45 years, continued to increase but at a slower rate between 45 and 60 years old and levelled off after the age of 60.

It seems counterintuitive that while physical activity increases through the 30s, 40s and 50s (figure 1, middle panel), BMI continues to increase during this period (figure 1, bottom panel). In addition, we found that women who did not meet current PA recommendations at baseline or those who were low fit at baseline had a higher BMI throughout adulthood than their active or fit peers, even though the BMI change pattern was similar among the two groups of women. We thought it worthwhile, therefore, to comment on these findings. Kohrt pointed out in a recent report that it is difficult to determine whether the increased propensity for weight gain at midlife is primarily a consequence of the menopause transition or of advancing age.[42] Other than energy expenditure, many factors play important roles in the regulation of body weight, including oestrogen, energy intake and loss of muscle mass.[42] Furthermore, the imperfect measure of physical activity in many studies, including the current study, and the use of BMI as a gross adiposity marker make it more difficult to disentangle the complex relationships between BMI and physical activity.

Strengths and limitations of the study

To the best of our knowledge, this is the first prospective study that concurrently assessed the association of PA, CRF and BMI with ageing in a large cohort of women using GAMM modelling techniques. These models have the advantage over repeated measure analysis of variance, linear mixed models (LMM) and other conventional growth modelling methods in that GAMM is more flexible in fitting the data and does not assume the presence of an average trajectory in the underlying population. Instead of forcing the data into a predefined model, the model follows the data and fits both linear and non-linear patterns of predictors. Although seldom used in epidemiological research, GAMM is a very powerful technique to deal with real-life complexities, and its use is now possible with free, user-friendly software.[43 44] Another major strength of the current study is that the modelled ageing trajectories were defined with data from across the adult lifespan. Other strengths include a prospective design and maximal exercise testing to quantify CRF.

The primary limitation is the use of self-reported PA. People tend to over-report their physical activity level, and the random measurement error for self-reported PA is more likely to be pronounced than the measurement error for CRF. However, the physical activity questionnaire used in the current study was not only valid, but also provided comparable classification results when compared with the current physical activity guideline.[45] Another limitation is that the study population consisted mainly of European-American women in the middle and upper socioeconomic strata. Participants in this study elected to visit the Cooper Clinic for a preventative medical evaluation, not for disease treatment purposes. They were likely to have better access to medical services and tended to be healthier and leaner than members of the general population. Thus, the results may not be generalisable to other adult populations. All epidemiological studies, even well-known cohorts such as the Nurses Health Study, Physicians Health Study and Harvard Alumni Study, must be concerned about possible selection bias or lack of representativeness of the study population, and this study is no exception. However, the homogeneity of the population sample in sociodemographic factors enhances the internal validity of the findings.

CONCLUSION

In summary, our data show that the age-related longitudinal patterns of physical activity and fitness are not linear, and that

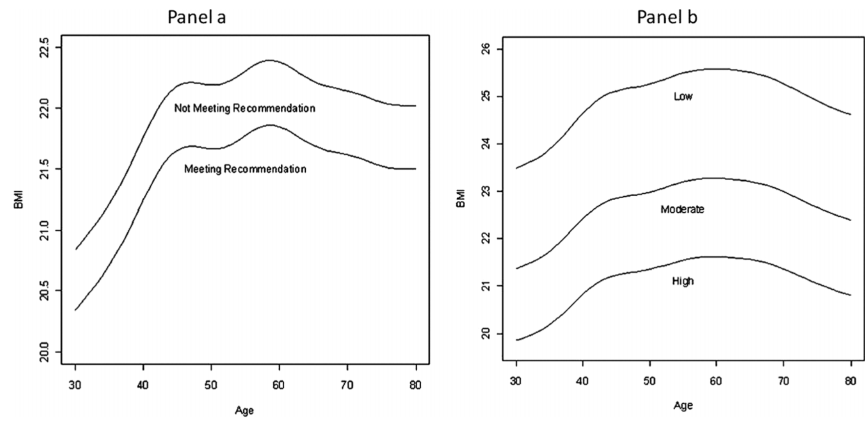

Figure 2 Body mass index change with age in women by baseline physical activity (meeting and not meeting recommendation) (panel A) and cardiorespiratory fitness (low, moderate and high) (panel B). It was assumed that the participants did not smoke.

baseline activity and fitness levels are associated with BMI status during adulthood, but do not affect BMI change patterns. The menopause transition seems to be a critical period to initialise and promote physical activity, especially for sedentary women, because the accelerated decline in both activity and fitness starts around this time. Although the ageing-associated decline in CRF cannot be avoided, usual physical activity is still its primary determinant.[46] The consensus public health guideline to obtain 150 min/week of moderate-intensity physical activity, such as brisk walking or jogging will improve women's fitness levels.

What is known

- Previous studies have shown that the age-associated changes in body weight, activity and fitness were nonlinear. However, these findings were often based on cross-sectional data.
- No studies simultaneously described the longitudinal trajectories of these exposures with ageing across the adult lifespan in a well-defined population-based sample of women.

What this study adds

- Both physical activity and fitness peak around 40–50 years old among women.
- Body mass index change pattern was not associated with the initial activity or fitness levels.
- Menopause transition seems to be a critical time window to initialise and promote physical activity.

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Ethics approval The Cooper Institute Institutional Review Board.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing The database to be used in this project was obtained by SB (one of the co-authors on the paper) as part of his separation agreement from the Cooper Institute in 2006. This agreement prevents us from sharing the data with other investigators. However, we pledge to collaborate with interested investigators on research using the database. This will involve the investigators submitting a proposal for a project; we will perform the analyses and provide tables and figures for the investigators to prepare scientific manuscripts. We will continue to assist with analyses during reviews and revisions of the manuscripts.

REFERENCES

1 Roubenoff R, Castaneda C. Sarcopenia-understanding the dynamics of aging muscle. *JAMA* 2001;286:1230–1.
2 Chumlea WC, Guo SS, Kuczmarski RJ, *et al*. Body composition estimates from NHANES III bioelectrical impedance data. *Int J Obes Relat Metab Disord* 2002;26:1596–609.
3 Ogden CL, Fryar CD, Carroll MD, *et al*. Mean body weight, height, and body mass index, United States 1960–2002. *Adv Data* 2004;347:1–17.
4 Centers for Disease Control and Prevention. Prevalence of self-reported physically active adults—United States, 2007. *Morb Mortal Wkly Rep* 2008;57:1297–300.
5 Fleg JL, Morrell CH, Bos AG, *et al*. Accelerated longitudinal decline of aerobic capacity in healthy older adults. *Circulation* 2005;112:674–82.
6 Jackson AS, Sui X, Hebert JR, *et al*. Role of lifestyle and aging on the longitudinal change in cardiorespiratory fitness. *Arch Intern Med* 2009;169:1781–7.
7 Hollenberg M, Yang J, Haight TJ, *et al*. Longitudinal changes in aerobic capacity: implications for concepts of aging. *J Gerontol A Biol Sci Med Sci* 2006;61:851–8.
8 Caspersen CJ, Pereira MA, Curran KM. Changes in physical activity patterns in the United States, by sex and cross-sectional age. *Med Sci Sports Exerc* 2000;32:1601–9.
9 Macera CA, Pratt M. Public health surveillance of physical activity. *Res Q Exerc Sport* 2000;71:S97–103.
10 Jackson AS, Janssen I, Sui X, *et al*. Longitudinal changes in body composition associated with healthy ageing: men, aged 20–96 years. *Br J Nutr* 2012;107:1085–91.
11 Roger VL, Go AS, Lloyd-Jones DM, *et al*. Heart disease and stroke statistics—2012 update: a report from the american heart association. *Circulation* 2012;125:e2–20.
12 Blair SN, Brodney S. Effects of physical inactivity and obesity on morbidity and mortality: current evidence and research issues. *Med Sci Sports Exerc* 1999;31:S646–62.
13 Lee DC, Sui X, Blair SN. Does physical activity ameliorate the health hazards of obesity? *Br J Sports Med* 2009;43:49–51.
14 DiPietro L. Physical activity, body weight, and adiposity: an epidemiologic perspective. *Exerc Sport Sci Rev* 1995;23:275–303.
15 Klesges RC, Klesges LM, Haddock CK, *et al*. A longitudinal analysis of the impact of dietary intake and physical activity on weight change in adults. *Am J Clin Nutr* 1992;55:818–22.
16 Williamson DF, Madans J, Anda RF, *et al*. Recreational physical activity and ten-year weight change in a US national cohort. *Int J Obes Relat Metab Disord* 1993;17:279–86.
17 Slattery ML, McDonald A, Bild DE, *et al*. Associations of body fat and its distribution with dietary intake, physical activity, alcohol, and smoking in blacks and whites. *Am J Clin Nutr* 1992;55:943–9.
18 Owens JF, Matthews KA, Wing RR, *et al*. Can physical activity mitigate the effects of aging in middle-aged women? *Circulation* 1992;85:1265–70.

19 Schmitz KH, Jacobs DRJ, Leon AS, *et al*. Physical activity and body weight: associations over ten years in the CARDIA study. Coronary Artery Risk Development in Young Adults. *Int J Obes Relat Metab Disord* 2000;24:1475–87.
20 Shephard RJ. Limits to the measurement of habitual physical activity by questionnaires. *Br J Sports Med* 2003;37:197–206.
21 Aadahl M, Kjaer M, Kristensen JH, *et al*. Self-reported physical activity compared with maximal oxygen uptake in adults. *Eur J Cardiovasc Prev Rehabil* 2007;14:422–8.
22 American College of Sports Medicine Position Stand. American College of Sports Medicine Position Stand. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. *Med Sci Sports Exerc* 1998;30:975–91.
23 Haskell WL, Leon AS, Caspersen CJ, *et al*. Cardiovascular benefits and assessment of physical activity and physical fitness in adults. *Med Sci Sports Exerc* 1992;24: S201–20.
24 Sidney S, Sternfeld B, Haskell WL, *et al*. Seven-year change in graded exercise treadmill test performance in young adults in the CARDIA study. Cardiovascular risk factors in young adults. *Med Sci Sports Exerc* 1998;30:427–33.
25 Jackson AS, Kampert JB, Barlow CE, *et al*. Longitudinal changes in cardiorespiratory fitness: measurement error or true change? *Med Sci Sports Exerc* 2004;36:1175–80.
26 Blair SN, Kohl HW III, Barlow CE, *et al*. Changes in physical fitness and all-cause mortality: a prospective study of healthy and unhealthy men. *JAMA* 1995;273:1093–8.
27 Kohl HW, Blair SN, Paffenbarger RS Jr,, *et al* A mail survey of physical activity habits as related to measured physical fitness. *Am J Epidemiol* 1988;127:1228–39.
28 Banda JA, Hutto B, Feeney A, *et al*. Comparing physical activity measures in a diverse group of midlife and older adults. *Med Sci Sports Exerc* 2010;42:2251–7.
29 Ainsworth BE, Haskell WL, Whitt MC, *et al*. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc* 2000;32: S498–504.
30 Physical Activity Guidelines Advisory Committee. Physical Activity Guidelines Advisory Committee Report. 2008. Ref Type: Internet Communication.
31 Balke B, Ware RW. An experimental study of physical fitness in Air Force personnel. *US Armed Forces Med J* 1959;10:675–88.
32 Pollock ML, Bohannon RL, Cooper KH, *et al*. A comparative analysis of four protocols for maximal treadmill stress testing. *Am Heart J* 1976;92:39–46.
33 Pollock ML, Foster C, Schmidt D, *et al*. Comparative analysis of physiologic responses to three different maximal graded exercise test protocols in healthy women. *Am Heart J* 1982;103:363–73.
34 Sui X, LaMonte MJ, Blair SN. Cardiorespiratory fitness and risk of nonfatal cardiovascular disease in women and men with hypertension. *Am J Hypertens* 2007;20:608–15.
35 Hastie TJ, Tibshirani RJ. *Generalized additive models*. New York: Chapman and Hall, 1990.
36 Wood SN. Thin plate regression splines. *J Royal Stat Soc* 2003;65:95–114.
37 Wood SN. Low rank scale invariant tensor product smooths for generalized additive mixed model. *Biometrics* 2006;62:1025–36.
38 US Department of Health and Human Services. *Healthy people 2010 (conference edition)*. US Government Printing Office, Superintendent of Documents, Washington, DC, 2000.
39 Brown WJ, Heesch KC, Miller YD. Life events and changing physical activity patterns in women at different life stages. *Ann Behav Med* 2009;37:294–305.
40 Kuczmarski RS, Flegal KM, Campbell SM, *et al*. Increasing prevalence of overweight among US adults: the National Health and Nutrition Examination Surveys, 1960 to 1991. *JAMA* 1994;272:205–11.
41 Kuczmarski RJ, Flegal KM. Criteria for definition of overweight in transition: background and recommendations for the United States. *Am J Clin Nutr* 2000;72:1074–81.
42 Kohrt WM. Menopause medicine: exercise and weight gain. *Geriatrics* 2009;64:28–9.
43 Lopes C, Andreozzi VL, Ramos E, *et al*. Modelling over week patterns of alcohol consumption. *Alcohol Alcohol* 2008;43:215–22.
44 Hemmi MH, Schneider S, Muller S, *et al*. Analyzing temporal patterns of infant sleep and negative affective behavior: a comparison between different statistical models. *Infant Behav Dev* 2011;34:541–51.
45 Stofan JR, DiPietro L, Davis D, *et al*. Physical activity patterns associated with cardiorespiratory fitness and reduced mortality: The Aerobics Center Longitudinal Study. *Am J Public Health* 1998;88:1807–13.
46 Ingelsson E, Larson MG, Vasan RS, *et al*. Heritability, linkage, and genetic associations of exercise treadmill test responses. *Circulation* 2007;115:2917–24.

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Xuemei Sui, Jiajia Zhang, Duck-chul Lee, Timothy S Church, Wenbin Lu, Junxiu Liu and Steven N Blair

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