The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences, 2025, **80(6)**, glaf059
https://doi.org/10.1093/gerona/glaf059
Advance access publication: 16 March 2025
Research Article

Reciprocal Associations Between Trajectories of Physical Activity and Physical Function Among Older Women: Findings From the Australian Longitudinal Study on Women's Health

Yuta Nemoto, PhD,[1,2,3,*] Wendy J. Brown, PhD,[4,5] Geeske Peeters, PhD,[6] and Gregore Iven Mielke, PhD[1]

[1]School of Public Health, The University of Queensland, Brisbane, Queensland, Australia.
[2]Department of Preventive Medicine and Public Health, Tokyo Medical University, Tokyo Japan.
[3]School of Health Innovation, Kanagawa University of Human Services, Kanagawa, Japan.
[4]Faculty of Health Sciences and Medicine, Bond University, Gold Coast, Australia.
[5]School of Human Movement and Nutrition Sciences, The University of Queensland, Brisbane, Queensland, Australia.
[6]Department of Geriatric Medicine, Radboud University Medical Center, Nijmegen, HB, The Netherlands.

[*]Address correspondence to: Yuta Nemoto, PhD. E-mail: y.nemoto@uq.edu.au

Decision Editor: Roger A. Fielding (Medical Sciences Section)

Abstract

Background: Although physical activity (PA) is known to improve physical function (PF), and functional decline impacts the capacity to engage in PA, the reciprocal relationship between PA and PF remains unclear.

Methods: Data were from participants in the 1921–1926 cohort of the Australian Longitudinal Study on Women's Health (*N* = 8 238). PA and PF were assessed at 3-year intervals from 1999 (73–78 y) to 2011 (85–90 y). Group-based trajectory modeling was used to identify PA and PF trajectories, and associations between PA and PF were examined using mixed-effects models and restricted cubic spline modeling.

Results: Three trajectories for PA and PF were identified: Low, Moderate, and High. Women in the High PA group maintained high PF and did not reach the starting PF level of the Low PA group (at age 73) until they were 87. Similarly, women in the High PF group maintained higher PA than those in the other groups. Women in the Low PF group never met PA guidelines and had PF scores below the disability threshold throughout the study. Restricted cubic splines showed that higher PA was associated with better PF 3 years later, and vice versa, indicating that PA and PF influence each other.

Conclusion: There are reciprocal relationships between PF and PA; higher levels of PA promote better PF, and higher PF may help slow the decline in PA. Although rates of decline in PF show little variation with PA in women during their 80s, habitually high PA confers considerable benefits, contributing to additional years of healthy life.

Keywords: Bidirectional relationships, Exercise, Life-course, Functional capacity, Healthy life expectancy

Physical function (PF) peaks in early adulthood, remains stable in the 20s and 30s and declines remarkably in older age (1,2). Although socioeconomic and other health characteristics are important (3–6), physical activity (PA) is recognized as a significant modifiable factor for improving PF and reducing the risk of physical disability with increasing age (7,8).

There are, however, several questions about the relationships between PF and PA, especially in older age. First, although PA is an important contributor to achieving optimal PF early in life (2), the associations between trajectories of PA and PF in mid-older age are not well understood. This reflects a paucity of prospective cohort studies with repeated measurements of both PA and PF. Our previous study demonstrated a remarkable decline in population-level PA over 15 years during later life (9). However, levels of PA at specific time points were not normally distributed, which supported to us that there may be several PA and PF trajectories among older women. In a previous study, we assessed changes in PF in three cohorts of women, from ages 18, 45, and 70, and described the relationships between PA at baseline with subsequent declines in PF over 15 years. We did not, however, consider any changes in PA during follow-up (1). Second, given that both PF and PA are likely to decline in old age (1,9), the relationships between the 2 may be reciprocal. Although others have examined the influence of PA on PF and of PF on PA (10,11), reciprocal relationships remain under-studied (12–15).

To address the existing literature gap regarding the reciprocal association between PF and PA, we examined (a) the trajectories of PA and PF from age 73 to 90, (b) the associations of trajectories of PA with PF decline and of trajectories of PF

Received: October 9 2024; Editorial Decision Date: March 1 2025.

with PA decline, and (c) temporal relationships between PA and PF using data with a 3-year time lag. We hypothesized that there are several PA and PF trajectories in older age, and the associations between their trajectories are reciprocal and affect the rate of decline in PA and PF.

Method

Participants

Data were from participants in the 1921–1926 cohort of the Australian Longitudinal Study on Women's Health (ALSWH) who were randomly selected from the Australian National Health database. The first survey was mailed in 1996 when participants were aged 70–75 (n = 12,432) (16). Those who completed the survey were generally representative of women the same age in the Australian population (17). Five follow-up surveys were conducted at 3-year intervals from 1999 (73–78 years) to 2011 (85–90 years). ALSWH has ethical approval from the Human Research Ethics Committees (HRECs) of the Universities of Newcastle and Queensland (approval number 2004000224). Further details have been described elsewhere (17), and full details of the study can be found at http://www.alswh.org.au.

Since the PA measure used in 1996 (Survey 1) was different from that in the following surveys, data from the second survey in 1999 were used as baseline in this study. Data from women who reported PA and PF data at least twice from 1999 to 2011 were included in the analyses (N = 8 238, 66.3%; Supplementary Figure 1).

Measurements

Physical activity

PA was assessed using the modified self-administered version of the Active Australia Survey, which has acceptable reliability and validity (18). In each survey, participants reported the frequency and duration of walking for transport or recreation, moderate-intensity and vigorous activities. Minutes per week spent in each activity were multiplied by a metabolic equivalent (MET) score (3.33 for walking and moderate-intensity activity or 6.66 for vigorous activity), and MET.minutes/week were summed to provide total PA.

Physical Function and Disability Thresholds

The PF subscale of the 36-item short-form health survey (SF-36), which consists of 10 items and has acceptable validity among older adults, was used (19). The participants reported to what extent their health conditions limited their daily tasks, including vigorous and moderate activity, climbing stairs, moving about and engaging in self-care. The responses were summed to calculate scores, which ranged from 0 (poor) to 100 (good).

The disability threshold was defined as the average PF score at the time when women first reported needing help with daily activities, such as grooming, eating, and bathing/showering, and other tasks. The calculated threshold was 67.3 in this cohort.

Covariates

Sociodemographic factors (area of residence, school graduation age, and ability to manage on income) and behavioral and health characteristics (body mass index (BMI), smoking status, alcohol status, personal illness or injury, surgery, and moving to institutional care) were selected as covariates based on previous studies (6,15,20). The list of variables and response options/categories are shown in Supplementary Table 1.

Statistical Analysis

We performed group-based trajectory modeling to identify trajectories of PA and PF using the Stata plugin traj (21). The model included PA or PF as the dependent variable and age (73–90y) as the independent variable. The number of groups and polynomials were determined based on the Bayesian information criterion, Akaike information criterion, and log-likelihood. The adequacy of the best-fit model was confirmed using posterior probabilities of group membership (> 0.7), and the odds of correct classification (> 5) (22). Full information maximum likelihood estimation was used to account for missing data. Medians and interquartile ranges of observed PA and PF at each age for each trajectory group were calculated.

Mixed-effects models with random intercept and slope were conducted to evaluate the associations between PA and PF. The models included standardized age and age-squared as a timescale variable, PF/PA as the dependent variable, and trajectories of PA/PF and their interaction terms with timescale (age and age-squared) as the independent variables. Covariates were selected based on the literature (6,20,23). The coefficient indicates the magnitude of the impacts of exposure on the outcome, and the interaction terms between the trajectories of PA/PF and timescale were interpreted as the differences in PA/PF decline in each PA/PF trajectory group. We confirmed the model assumptions, including normality of residuals and homoscedasticity, which were checked using quantile-quantile plots and the residuals against the fitted values (24). PF and PA data at each age from 73 to 90 were estimated based on the results of the mixed-effects models, and average values and 95% confidence intervals (CI) for each trajectory were calculated.

To determine whether the temporal association between PA and PF is a dose–response relationship and whether it is linear or nonlinear, restricted cubic spline functions with 4 knots were fitted to mixed-effects models with a 3-year time-lag. The number of knots was determined based on the Akaike information criterion. Two analysis models were used: the first included PA at Survey 2–5 (1999–2008) as the exposure, with PF at Survey 3–6 (2002–2011) as the outcome; the second included PF at Survey 2–5 (1999–2008) as the exposure, with PA at Survey 3–6 (2002–2011) as the outcome. Each model was adjusted for time-invariant variables (years of schooling, area of residence, smoking and drinking status) and time-varying variables (ability to manage on income, BMI, major personal illness or injury, major surgery, moving to institutional care, and the previous outcome variable value). The assumptions of mixed-effects models were confirmed using the methods described earlier.

As the prevalence of participants with missing values for any variables in the multivariable analyses was 32.2% (for PA) and 32.6% (for PF), we created 20 data sets using multiple imputation (R package MICE (25)) (26), and combined the estimates using Rubin's rules. For further details, refer to Supplementary Figures 2 and 3 (27).

Group-based trajectory modeling was conducted using Stata 16.0 (StataCorp, LLC, College Station, TX). Mixed-effects models and multiple imputation were conducted using R 4.3.1 (R Foundation for Statistical Computing, Vienna, Austria). We have reported the statistical analyses following the checklist for statistical assessment of medical papers (28).

Results

Characteristics of the women whose data were included (analytic sample) and those whose data were not included (nonanalytic sample) at age 70–75 are shown in Supplementary Table 2. Both groups had similar characteristics, with the exception of low years of schooling and experience of major illness or injury, which were more prevalent in the nonanalytic sample than in the analytic sample (Supplementary Table 2).

Trajectories of PA from age 73 to 90 are shown in Figure 1, the goodness-of-fit of the models are shown in Supplementary Table 3, and observed median PA values at each age, in each trajectory group are shown in Supplementary Table 4. Note that PA levels in Figure 1 and Supplementary Table 4 differ as the figure presents estimated averages and the table shows the observed median values. We employed 3 groups of cubic models, which had acceptable adequacy, to identify the trajectories of PA, which were labeled as Low PA (26.0% of participants), Moderate PA (58.3%), and High PA (15.7%) (Figure 1 and Supplementary Table 3). In the Low PA group, median PA levels were 0 at every age. Median PA in the moderate PA group gradually declined from 533 MET.minutes/week to 0 at age 89. Women in the high trajectory group maintained very high PA (> 1600 MET.minutes/week) until age 82. This was followed by a gradual decline to 200 MET.minutes/week at age 90 (Figure 1, Supplementary Table 4).

Characteristics of participants in each PA trajectory group are shown in Supplementary Table 5. Women in the High PA group were more likely than those in the Low group to be in the underweight/normal BMI category, and to be low-risk drinkers. They were also less likely to have fewer years of schooling, to be nondrinkers, and to be in the obese BMI category (Supplementary Table 5).

Estimated PF at each age for each PA trajectory group is shown in Figure 2, with data in Supplementary Tables 6 and 7. The mixed-effects model showed significant interactions between PA trajectories and age, indicating that the rate of decline in PF differed among PA trajectories (see Supplementary Table 6). The estimated PF in the Low PA group was below the disability threshold at every age. Although the annual decline in PF from age 73 to 90 was similar among groups, in the Low group the rate of PF decline was slightly higher from age 73–80 than after age 80, but in the High and Moderate groups the rate of decline was higher after age 80 than before (Figure 2 and Supplementary Table 7).

Trajectories of PF from age 73–90 are shown in Figure 3, with data shown in Supplementary Table 8 and 9. The best-fit model identified three PF trajectories: Low PF (29.2% of participants), Moderate PF (39.3%), and High PF (31.5%). In the low PF group, PF was already below the disability threshold at age 73 and continued to decline until age 88. In the Moderate PF group, PF scores were just above the disability threshold at age 73 and declined gradually until age 89. In the High PF group, scores were consistently high until age 82, after which they declined to 62.5.

Characteristics of participants in each PF trajectory group are shown in Supplementary Table 10. Women in the High PF group were more likely than those in the Low group to be better able to manage on their income, to be in the underweight/normal BMI category, and to be low-risk drinkers. They were also less likely to have <14 years of schooling, to be obese, to be nondrinkers, and to have experienced a major personal illness or injury and major surgery (Supplementary Table 10).

Estimates of PA at each age for each PF trajectory are shown in Figure 4, with data in Supplementary Tables 11 and 12. The rate of decline in PA differed in the three PF trajectory groups (Supplementary Table 11). At age 73, estimated PA in the Low PF group was below the lower level of the PA guidelines (29), in the Moderate PF group it was above the

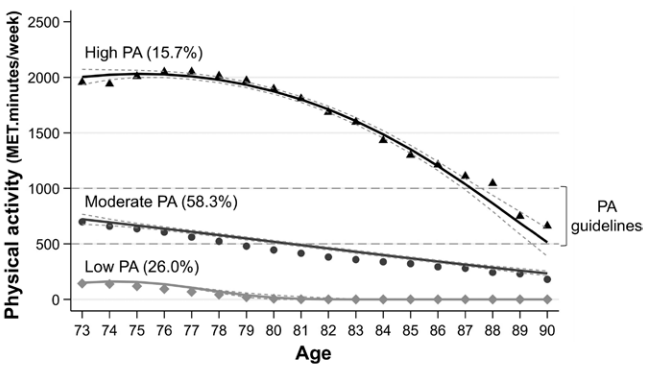

Figure 1. Trajectories of observed physical activity from age 73 to 90 (n = 8 238). Group-based trajectory modeling was conducted, including physical activity as the dependent variable and age (73–90 years) as the independent variable. The trajectories in the figure present the estimated averages and confidence intervals. Outliers (defined as > 4 000 MET.minutes/week, which is 4 times higher than the upper level of current PA guidelines) were truncated to 4 000 MET.minutes/week. PA = physical activity.

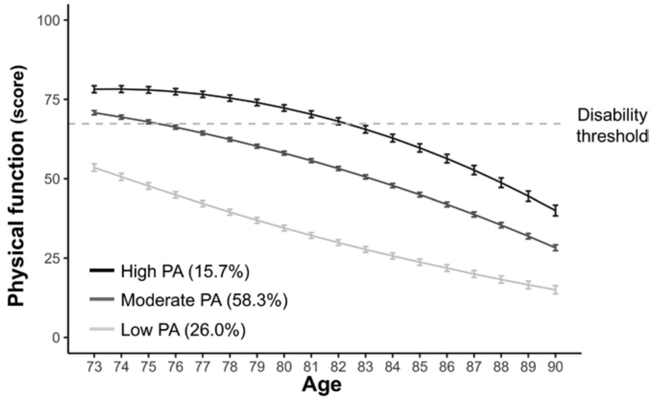

Figure 2. Estimated physical function at each age for each physical activity trajectory (n = 8 238). Physical function (PF) at each age was estimated based on mixed-effects models with random intercept and random slope. The model included standardized age and age-squared as timescale variables, PF as the dependent variable, and physical activity (PA) trajectories and their interaction terms with timescale (age and age-squared) as the independent variables, and time-invariant variables (education, residential area, smoking, and drinking status) and time-varying variables (ability to manage on income, BMI, major personal illness or injury, major surgery, and moving to institutional care) as the covariates. Average and 95% confidence intervals for each PA trajectory were calculated. The disability threshold (67.3) was defined as the average PF score at the time when women first reported requiring help with daily activities, such as grooming, eating, bathing/showering, dressing, getting up from a chair, walking inside the house, using the toilet, shopping for groceries, doing light or heavy housework, managing money, preparing meals, taking medications, using the telephone, and engaging in leisure activities or hobbies. BMI = body mass index.

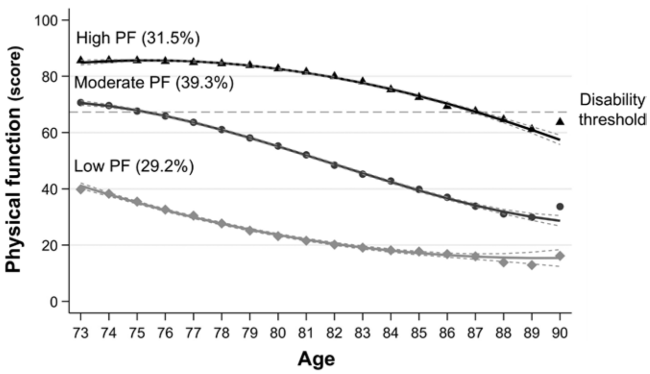

Figure 3. Trajectories of observed physical function from age 73 to 90 (n = 8 238). Group-based trajectory modeling was conducted, including physical function as the dependent variable and age (73–90 years) as the independent variable. The trajectories in the figure present the estimated averages and confidence intervals. The disability threshold (67.3) was defined as the average PF score at the time when women first reported requiring help with daily activities, such as grooming, eating, bathing/showering, dressing, getting up from a chair, walking inside the house, using the toilet, shopping for groceries, doing light or heavy housework, managing money, preparing meals, taking medications, using the telephone and engaging in leisure activities or hobbies. PF = physical function.

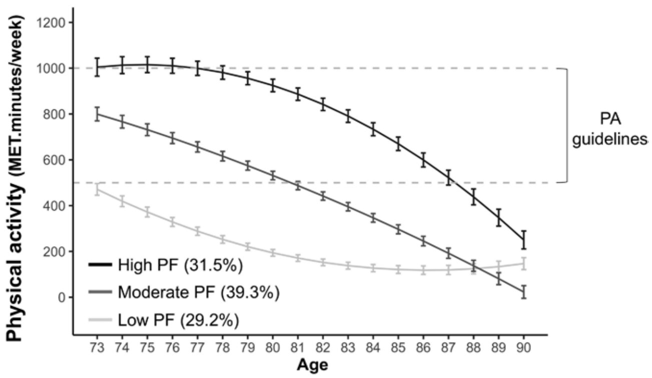

Figure 4. Estimated physical activity at each age for each physical activity trajectory (n = 8 238). Physical activity (PA) at each age was estimated based on mixed-effects models with random intercept and random slope. The model included standardized age and age-squared as timescale variables, PA as the dependent variable, and physical function (PF) trajectories and their interaction terms with timescale (age and age-squared) as the independent variables, and time-invariant variables (education, residential area, smoking and drinking status) and time-varying variables (ability to manage on income, BMI, major personal illness or injury, major surgery, and moving to institutional care) as the covariates. Average and 95% confidence intervals for each PF trajectory were calculated. BMI = body mass index.

lower level of the PA guidelines, and in the High PF group it was above the upper level of the PA guidelines. Throughout the study, the rate of decline in PA was almost linear in the Moderate PF group. However, in the High group, the rate of decline was lower in the first seven years, and in the Low group the rate was lower after age 80.

Temporal relationships between PA and PF are shown in Figure 5. Restricted cubic spline modellings showed dose-response and nonlinear relationships between PA and PF, PF increased markedly as PA increased from 0 to 1000 MET.minutes/week, and PA increased markedly with increasing PF score from 40 to 100 (Figure 5).

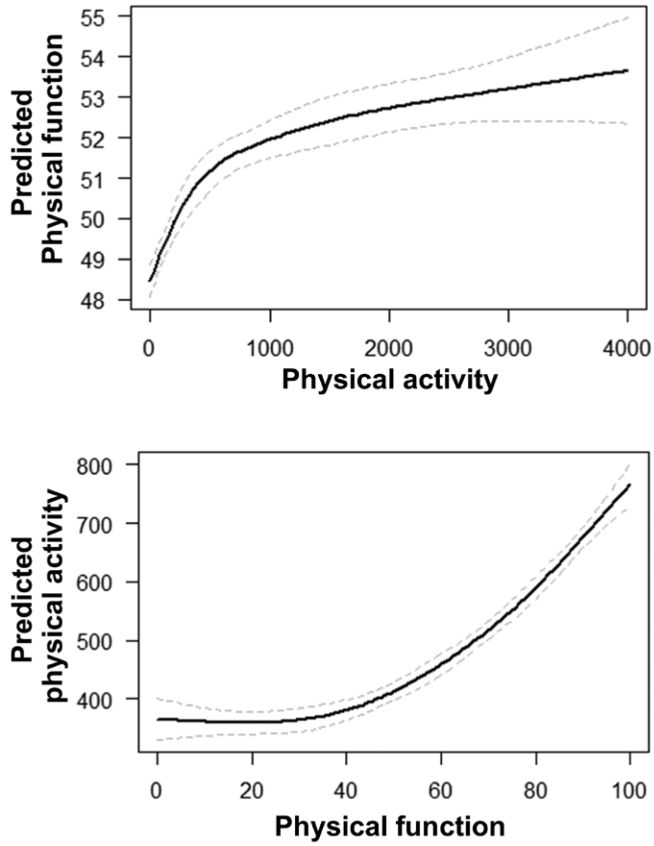

Figure 5. Temporal relationships between physical activity and physical function (n = 8 238). Restricted cubic spline functions with 4 knots were fitted to mixed-effects models with a 3-year time-lag. Mixed-effects model included time-invariant covariates (years of schooling, area of residence, smoking and drinking status) and time-varying covariates (ability to manage on income, BMI, major personal illness or injury, major surgery, moving to institutional care, and the previous outcome variable value) in the models. The solid black line represents the predicted values from the mixed-effects model, whereas the dashed lines indicate the 95% confidence intervals. Top figure: The model included physical activity between Survey 2 (1999) and Survey 5 (2008) as the exposure, with physical function between Survey 3 (2002) and Survey 6 (2011) as the outcome. Bottom figure: The model included physical function between Survey 2 (1999) and Survey 5 (2008) as the exposure, with physical activity between Survey 3 (2002) and Survey 6 (2011) as the outcome. BMI = body mass index.

Discussion

This study is the first to examine the reciprocal relationships between trajectories of PA and PF among older women. A data-driven categorization approach identified 3 trajectories of both PA and PF in women over 17 years from age 73 to 90. Our prospective data showed marked associations between activity and function over time, with remarkably high PA associated with maintenance of high levels of PF until the women were in their early 80s. In contrast, the low-active women had functional scores below the disability threshold over the entire study. When the data were time-lagged, PA was associated with PF three years later, and vice versa, indicating prospective relationships between these variables, with each affecting the other reciprocally.

Trajectories of PA and Its Associations With PF in Later Life

Although the patterns of decline in PA varied, all trajectory groups showed a declining trend over time, consistent with the population-level decline in PA observed later in life among Australian women (9). Nevertheless, PA levels in the High PA group were maintained well above the current PA guidelines, and their rate of PF decline was lower than in the other two groups, especially during their seventies. As a result, this group did not reach the starting PF level of the Low group (53.7 at age 73) until they were age 87 (52.9). PF was higher in the high PA trajectory group throughout the study, reflecting both the high baseline scores and the lower rate of decline before age 80. Our earlier ALSWH study also showed changing rates of PF decline after age 70, according to PA levels at age 70 (1).

Trajectories of PF and Associations With PA in Later Life

The trajectories of decline in PF were very similar to those for PA, with overall declines over time, consistent with the population-level trends among older women (1). However, PF levels in the High PF group declined more slowly than in the other groups, especially before age 80, so that this group maintained relatively high PF scores than the other groups. In contrast, the rate of decline in the Low PF group was higher before age 80, with very low PF after the age of 80.

In the High PF group, the lower decline in PF until about age 80 was consistent with maintenance of very high PA levels during the 70s. Although many intervention studies have reported that aerobic, balance, and resistance training improve PF among older adults in the short term (30,31), our findings suggest that the rate of PF decline after age 80 is fairly consistent, so that PF levels really do depend on starting values, which appear to be strongly related to habitual PA levels earlier in life (32).

Temporal Relationships Between PA and PF

In the time-lagged cubic spline models, we found reciprocal dose–response and nonlinear relationships between PA and PF. The EPIC-Norfolk researchers have reported bidirectional relationships between PA and PF, highlighting associations between changes in PA and PF as well as between baseline PA/PF and PF/PA after six years (15). Our findings similarly indicate associations between changes in PA and PF and temporal relationships between PA and PF over a 12-year period, supporting the long-term reciprocal relationships between PA and PF among older women.

Strengths and Limitations

The main strength of this study is the use data from a nationally representative cohort study, with a high retention rate of surviving participants. The response rate among eligible participants at ages 85–90 (excluding data from participants who had died or withdrawn between 1996 and 2011) was high (80.9%). The study used the same validated methods to assess PA and PF at three-year intervals for 17 years.

This study has several limitations. First, we obtained data on PA and PF using self-report measures. Although self-report surveys may overestimate PA and PF levels, our measures demonstrate acceptable reliability and validity (18,19,33). Second, although similar characteristics between the analytical and nonanalytical samples were observed, healthy survivor bias could have occurred because the participants were aged 73 at baseline, and only data from those with PA and PF measurements at least two time points were included in the analyses.

Conclusion

Our findings suggest that there are long-term reciprocal relationships between PF and PA, with possible “causal loops” between activity and function; higher levels of PA promote better PF and higher PF may help to slow the decline in PA during older age. Although habitually high levels of PA confer considerable benefits in terms of additional years of healthy life, rates of decline in PF do not vary greatly with PA when women are in their eighties. The PF benefits therefore appear to accrue from getting more PF “in the bank” through higher levels of PA earlier in life, and from maintaining high levels of PA for as long as possible into older age.

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences* online.

Funding

The Australian Longitudinal Study on Women’s Health is funded by the Australian Government Department of Health. Y.N. is supported by a postdoctoral research fellowship from the Japan Society for the Promotion of Science (22J00945). G.I.M. is supported by a National Health and Medical Research Council Investigator Grant (APP2008702). The organizations named here had no influence on study design; data collection, data analysis; or preparation of the manuscript.

Conflict of Interest

The authors declare that they have no conflict of interest.

Data Availability

The dataset analyzed in this study was provided by The Australian Longitudinal Study of Women’s Health. Information on how to access the data can be found at https://www.alswh.org.au/how-to-access-the-data/alswh-data.

Acknowledgments

The research on which this paper is based was conducted as part of the Australian Longitudinal Study on Women’s Health by the University of Queensland and the University of Newcastle. We are grateful to the Australian Government Department of Health and Aged Care for funding and to the women who provided the survey data.

Author Contributions

W.J.B. contributed to the design of the ALSWH and acquisition of data, all authors were involved in the conception and design of this study, Y.N. and G.I.M. conducted the analyses, all authors interpreted the data; Y.N. prepared the first draft, and all authors critically reviewed and revised. All authors approved the final manuscript.

References

1. Peeters G, Dobson AJ, Deeg DJ, et al. A life-course perspective on physical functioning in women. *Bull World Health Organ*. 2013;91(9):661–70. https://doi.org/10.2471/BLT.13.123075

2. Kalache A, Kickbusch I. A global strategy for healthy ageing. *World Health*. 1997;50(4):4–5.
3. Zhao Y, Duan Y, Feng H, et al. Trajectories of physical functioning and its predictors in older adults: a 12-year longitudinal study in China. *Front Public Health*. 2022;10:923767. https://doi.org/10.3389/fpubh.2022.923767
4. Jayanama K, Theou O, Godin J, et al. Relationship of body mass index with frailty and all-cause mortality among middle-aged and older adults. *BMC Med*. 2022;20(1):404. https://doi.org/10.1186/s12916-022-02596-7
5. Rowe JW, Kahn RL. Successful aging. *Gerontologist*. 1997;37(4):433-40. https://doi.org/10.1093/geront/37.4.433
6. Peeters G, Beard JR, Deeg DJH, et al. Longitudinal associations between lifestyle, socio-economic position and physical functioning in women at different life stages. *Eur J Ageing*. June, 2019;16(2):167–179. https://doi.org/10.1007/s10433-018-0484-1
7. Chase J-AD, Phillips LJ, Brown M. Physical activity intervention effects on physical function among community-dwelling older adults: a systematic review and meta-analysis. *J. Aging Phys. Act*. 2017;25(1):149–170. https://doi.org/10.1123/japa.2016-0040
8. Bauman A, Merom D, Bull FC, et al. Updating the evidence for physical activity: summative reviews of the epidemiological evidence, prevalence, and interventions to promote "active aging." *Gerontologist*. April, 2016;56(Suppl 2):S268–80. https://doi.org/10.1093/geront/gnw031
9. Brown WJ, Pavey T. Physical activity in mid-age and older women: lessons from the Australian Longitudinal Study on Women's Health. *Kinesiol. Rev*. 2016;5(1):87–97. https://doi.org/10.1123/kr.2015-0057
10. Franco MR, Tong A, Howard K, et al. Older people's perspectives on participation in physical activity: a systematic review and thematic synthesis of qualitative literature. *Br J Sports Med*. October, 2015;49(19):1268–76. https://doi.org/10.1136/bjsports-2014-094015
11. Gómez-Redondo P, Valenzuela PL, Morales JS, et al. Supervised versus unsupervised exercise for the improvement of physical function and well-being outcomes in older adults: a systematic review and meta-analysis of randomized controlled trials. *Sports Med*. July, 2024;54(7):1877–1906. https://doi.org/10.1007/s40279-024-02024-1
12. Barone Gibbs B, Sternfeld B, Whitaker KM, et al. Bidirectional associations of accelerometer-derived physical activity and stationary behavior with self-reported mental and physical health during midlife. *Int J Behav Nutr Phys Act*. June 6, 2021;18(1):74. https://doi.org/10.1186/s12966-021-01145-4
13. Metti AL, Best JR, Shaaban CE, et al. Longitudinal changes in physical function and physical activity in older adults. *Age and Ageing*. 2018;47(4):558–564 https://doi.org/10.1093/ageing/afy025
14. Cooper A, Lamb M, Sharp SJ, et al. Bidirectional association between physical activity and muscular strength in older adults: results from the UK Biobank study. *Int J Epidemiol*. February 1, 2017;46(1):141–148. https://doi.org/10.1093/ije/dyw054
15. Yerrakalva D, Hajna S, Wijndaele K, et al. Bidirectional associations of accelerometer-assessed physical activity and sedentary time with physical function among older English adults: the EPIC-Norfolk cohort study. *Eur. J. Ageing*. 2022;19(4):1507–1517. https://doi.org/10.1007/s10433-022-00733-y
16. Lee C, Dobson AJ, Brown WJ, et al. Cohort profile: the Australian Longitudinal Study on Women's Health. *Int J Epidemiol*. October, 2005;34(5):987–91. https://doi.org/10.1093/ije/dyi098
17. Dobson AJ, Hockey R, Brown WJ, et al. Cohort Profile Update: Australian Longitudinal Study on Women's Health. *Int J Epidemiol*. October, 2015;44(5):1547,1547a–1547f. https://doi.org/10.1093/ije/dyv110
18. Heesch KC, Hill RL, van Uffelen JG, et al. Are active Australia physical activity questions valid for older adults? *J Sci Med Sport*. 2011;14(3):233–7 https://doi.org/10.1016/j.jsams.2010.11.004
19. Walters SJ, Munro JF, Brazier JE. Using the SF-36 with older adults: a cross-sectional community-based survey. *Age Ageing*. July, 2001;30(4):337–43. https://doi.org/10.1093/ageing/30.4.337
20. 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. https://doi.org/10.1007/s12160-009-9099-2
21. Jones BL, Nagin DS. A Stata plugin for estimating group-based trajectory models. Accessed October, 2022. https://kilthub.cmu.edu/ndownloader/files/11899808. https://kilthub.cmu.edu/articles/journal_contribution/A_Stata_Plugin_for_Estimating_Group-Based_Trajectory_Models/6470963
22. Nagin DS, Odgers CL. Group-based trajectory modeling in clinical research. *Annu Rev Clin Psychol*. 2010;6:109-38. https://doi.org/10.1146/annurev.clinpsy.121208.131413
23. Yerrakalva D, Hajna S, Wijndaele K, et al. Bidirectional associations of accelerometer-assessed physical activity and sedentary time with physical function among older English adults: the EPIC-Norfolk cohort study. *Eur J Ageing*. December, 2022;19(4):1507–1517. https://doi.org/10.1007/s10433-022-00733-y
24. Harrison XA, Donaldson L, Correa-Cano ME, et al. A brief introduction to mixed effects modelling and multi-model inference in ecology. *PeerJ*. 2018;6:e4794. https://doi.org/10.7717/peerj.4794
25. Buuren Sv, Groothuis-Oudshoorn K. Mice: multivariate imputation by chained equations in R. *J. Stat. Softw.* 2011;45(3)https://doi.org/10.18637/jss.v045.i03
26. Pedersen AB, Mikkelsen EM, Cronin-Fenton D, et al. Missing data and multiple imputation in clinical epidemiological research. *Clin Epidemiol*. 2017;9:157–166. https://doi.org/10.2147/CLEP.S129785
27. Rubin DB. *Multiple Imputation for Nonresponse in Surveys*. John Wiley & Sons, Inc.; 2004.
28. Mansournia MA, Collins GS, Nielsen RO, et al. A Checklist for statistical assessment of medical papers (the CHAMP statement): explanation and elaboration. *Br J Sports Med*. September, 2021;55(18):1009–1017. https://doi.org/10.1136/bjsports-2020-103652
29. Bull FC, Al-Ansari SS, Biddle S, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *Br J Sports Med*. December 2020;54(24):1451–1462. https://doi.org/10.1136/bjsports-2020-102955
30. de Labra C, Guimaraes-Pinheiro C, Maseda A, et al. Effects of physical exercise interventions in frail older adults: a systematic review of randomized controlled trials. *BMC Geriatr*. 2015;15(1):154. https://doi.org/10.1186/s12877-015-0155-4
31. Shen Y, Shi Q, Nong K, et al. Exercise for sarcopenia in older people: a systematic review and network meta-analysis. *J Cachexia Sarcopenia Muscle*. June, 2023;14(3):1199–1211. https://doi.org/10.1002/jcsm.13225
32. Nguyen B, Clare P, Mielke GI, et al. Physical activity across midlife and health-related quality of life in Australian women: a target trial emulation using a longitudinal cohort. *PLoS Med*. 2024;21(5):e1004384 https://doi.org/10.1371/journal.pmed.1004384
33. Timperio A, Salmon J, Rosenberg M, et al. Do logbooks influence recall of physical activity in validation studies? *Med Sci Sports Exerc*. July, 2004;36(7):1181–6. https://doi.org/10.1249/01.mss.0000132268.74992.d8