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Perspective review

Physical activity research in the first 15 years of the "45 and Up" cohort study: a narrative review and citation analysis

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Key points

- Analysis of studies on physical activity using data from the 45 and Up Study shows that Study participants are a highly active cohort, with three-quarters meeting World Health Organization recommended physical activity levels
- A citation review found that 19 of 92 peer-reviewed physical activity papers using 45 and Up Study data were cited more than 50 times, indicating good usage of physical activity measures in this cohort
- Future 45 and Up Study research recommendations include better use of the serial measures of physical activity in this cohort, increased standardisation of physical activity estimates, and using physical activity data to explore activity patterns over time in relation to health outcomes

Abstract

Background: The 45 and Up Study (the Study) is the largest study of healthy ageing in Australia and one of the biggest in the world. This review considered papers on physical activity in the first 15 years since the cohort was launched.

Methods: This narrative review extracted papers in the Study inventory of publications and supplemented by searches in Scopus and Medline databases.

Results: A total of 114 papers were identified, but after dual assessor extraction, 92 published articles were included that used physical activity as an exposure or outcome measure or reported physical activity prevalence in the sample studied. Results indicated that half of these physical activity studies used a cross sectional design. The 45 and Up survey responders were a highly active group, with three quarters meeting WHO recommended levels of physical activity. Optimal use of the longitudinal nature of this cohort linked physical activity exposures to a range of new health, environmental and wellbeing outcomes, and these papers were the most cited among 45 and Up physical activity papers. Nineteen of these 92 papers have been cited 50+ times, indicating good usage of 45 and Up physical activity data by the field.

Discussion & Conclusion: Physical activity-related research has been an important part of the overall output of the 45 and Up Study, but recommendations for future research include greater use of the longitudinal nature of the cohort, more standardisation in the way physical activity estimates are described, and using waves of the 45 and Up Study physical activity data to explore patterns of activity over time as the exposure variable in relation to health outcomes.

Introduction

Physical activity (PA) is important for chronic disease prevention and health promotion. PA reduces the risk of noncommunicable disease and improves brain health, mental health and wellbeing throughout the lifespan. It also reduces frailty, prevents falls in older adults, and reduces the severity and consequences of COVID-19 infection.[1-4] Ongoing epidemiological research using measures of PA, active travel, sitting time and total 24-hour movement behaviour has proliferated, providing a plethora of evidence to support public health action.[5] Nonetheless, global trends and Australian data suggest that PA levels have not increased substantially in recent decades [6,7].This is despite the impetus provided by the increased and diversified evidence base, as well as global policy documents; the latter include, but are not limited to, the *US Surgeon General's Report on Physical Activity* in 1996, the World Health Organization (WHO) *Global Strategy on Diet, Physical Activity and Health* in 2004, and the *WHO Global Action Plan on Physical Activity* (GAPPA) in 2018.[8-10]

The 45 and Up Study (hereafter 'the Study') was to establish and follow a large cohort of New South Wales (NSW) adults, link data to innovative health outcomes and administrative datasets, and provide new insights into population health and health services. It was designed as one of the largest cohort studies assembled in Australia and focused on the age groups likely to develop chronic conditions to inform prevention and health services in NSW. The Study was launched in 2006, and the baseline survey included the established and validated Active Australia survey questions to assess PA.[11,12] This measure asked about walking, moderate and vigorous intensity activity reported over the previous 7 days, including questions about total duration and number of sessions. The Active Australia questions assessed leisure-time PA and active travel but did not include questions about work-related or domestic time spent in PA. In addition, the established International Physical Activity Questionnaire (IPAQ) single-item question on time spent sitting was asked at baseline.[13] The PA questions were repeated in subsequent waves of the Study surveys. The initial follow-up of the first 100,000 participants was known as the SEEF study in 2010–2011, with the remainder followed up from 2012–2015[14]. The third wave of the Study in 2018–2020 included these PA questions. PA was included as an exposure variable to assess its longitudinal relationship to health and wellbeing outcomes.

The purpose of this perspective review paper is to describe how researchers have used PA measures in the Study research from the cohort's inception to 2022. The objectives are to describe how PA is used in the Study, describe the study designs used in these papers, summarise the PA prevalence estimates in these samples and estimate the impact of these publications through a review of their citation numbers.

Methods

We included peer-reviewed publications using data from the Study that used PA as an exposure or outcome measure, or studies that reported effect modification by PA or where studies reported the prevalence of PA in their sample. We excluded published abstracts and measurement development projects. We included studies that reported any physical activity estimates using Study data. We reported on walking or moderate to vigorous physical activity (MVPA), and those studies that reported total PA or meeting physical activity guidelines (PAGs) or stated the single-item sitting question asked.[13]

As a perspective article, we did not intend to systematically review the literature; instead, we conducted a narrative review to describe the scope of the published PA papers from the Study. Therefore, we used a targeted sampling approach by first utilising the publication list from the Sax Institute (the host institution for the Study); their website included around 480 peer-reviewed publications at the time of analysis. We then conducted an independent search in Scopus and Medline databases using the term "45 and Up" as well as any (title/keyword/abstract) use of the words "physical activit*, walk*, fitness, exercise, sedentary, sitting. After removing duplicates, the two search strategies identified 106 papers for full extraction. Two raters screened these papers (AB, KL), and 14 were removed, leaving 92 for data extraction.

Two raters extracted data and entered into a Microsoft Excel document (AB, KL). To describe the ways physical activity was used in the Study publications, we extracted:

- Author/publication date
- Which surveys from the Study were used/ data linkage
- Approximate sample size analysed in each paper
- Summary of the research question asked
- Measures of PA described
- Reported PA prevalence in the study sample
- Conclusions of the Study from a PA perspective

Sitting time was noted where possible.

Coding of each of these extracted fields was as follows: the Study surveys were described as baseline (B), first follow-up Social, Economic and Environmental Factors project (SEEF 2010); those not followed-up in the SEEF study were followed up from 2012 (wave 2, W2), with no papers yet utilising wave 3 data (2018–2020). Cohort data could be linked to all-cause and cause-specific mortality data, disease incidence data, hospital admission data, and other routine medical and pharmaceutical databases (Medical Benefits Schedule [MBS], Pharmaceutical Benefits Schedule [PBS]).

The Study designs were characterised as:

- Cross-sectional studies
- Aetiological cohorts studying disease incidence, cause specific hospital admission or mortality risk

- Cohorts linked to clinical procedures, medical or pharmaceutical benefits, or to self-report behaviour change across waves of the study
- Intervention sub-studies
- Other designs, including measurement studies, mediator or moderator analyses.

Physical activity measures were characterised as follows:

- Sessions of PA
- Minutes of PA
- Meeting PA guidelines or thresholds
- Other metrics.

Sessions of PA in the Study have been described as an accurate measure[15], although WHO guidelines typically report PA minutes per week to achieve recommended levels. Meeting PA guidelines was operationalised in different ways across studies, either as the current guideline of '150 minutes of at least moderate intensity activity per week' [16], using the earlier guidelines of 'at least five sessions and 150 minutes per week'[17], or using the 1980s guidelines (three sessions, 150 mins), or reporting "meeting recommendations" without specifying the method. For comparability, an attempt was made to collect information on low or insufficient levels of PA or not meeting guidelines across studies. For sessions, this was variously characterised as less than five sessions a week or less than seven sessions a week, and for minutes of PA, typically less than 150 minutes a week. This enabled a comparison of the prevalence of inactivity/insufficient activity across study samples. A summary was provided, which applied a physical activity lens to identify the contribution that physical activity made to each paper. These data are shown for all articles in Supplementary Table 1, available from: https://figshare.com/articles/journal_contribution/Supplementary_Table_1_details_of_included_studies_pdf/21514398

Finally, the number of times each paper was cited was obtained from the Scopus database for each article up to September 2022. Analysis was descriptive; general linear modelling (GLM) was used (SPSS 28) to assess mean citation numbers by study design adjusting for the publication period.

Results

A total of 114 papers were identified, 8 were duplicates, and of the remaining 106 papers were read in full for data extraction but 14 of them were subsequently excluded if PA-specific analyses were not a focus of the article or if PA was only a covariate in analysis, or if no prevalence data on PA participation was able to be estimated from the published results. The remaining 92 papers were used in this summary to describe the PA legacy to date of the Study, but the tabulated extracted data for all 106 articles (with their references) is shown in Supplementary Table 1, available from: https://figshare.com/articles/journal_contribution/Supplementary_Table_1_details_of_included_studies_pdf/21514398

The publication period showed a peak of PA related publications between 2014 and 2018 (Table 1). Of the

Table 1. Summary of extracted 45 and Up Study data from physical activity (PA) papers (N = 92 studies unless otherwise stated)

Characteristics from PA papers	*n* (%)	
Publication period		
2008–2013	22 (23.9)	
2014–2018	37 (40.2)	
2019–2022	33 (35.9)	
45 and Up surveys used (n = 91)[a]		
Baseline only	44 48.3)	
Baseline and SEEF	8 (8.8)	
Baseline, SEEF and W2	4 (4.4)	
Baseline + linked data	35 (38.5)	
Study design used		
Cross-sectional[b]	45 (48.5)	
Cohort (aetiological)[c]	30 (32.6)	
Cohort (health services)[d]	14 (15.2))	
Other[e]	3 (3.3	
Physical activity measures		
Sessions/week	27 (29.7)	
Minutes of PA	17 (18.7)	
PA guidelines	32 (35.2)	
Other, percentiles	15 (16.5)	
Sample size, low PA prevalence and citations of extracted data		
	Mean (SD)	Median (interquartile range)
Approx. sample size (1000s)	114.4 (91.6)	93 (31,205)
Low active/insufficient PA prevalence (%) estimates	30.1 (13.1)	26.9 (19.6,33.0)
Citations up to 2021 (Scopus[f])	40.1 (87.7)	15.0 (4,43)

PA = physical activity; SD = standard deviation

[a] One study reported a substudy sampled from the cohort, which involved physical activity, but did not use actual 45 and Up Study data

[b] Cross-sectional study design

[c] Cohort (aetiological): linked to mortality, disease incidence;

[d] Cohort (health services): linked to clinical procedures, costs, behaviour change

[e] Other: mediator, moderator and other designs

[f] Scopus: database of peer reviewed literature (available from: https://www.scopus.com/home.uri)

92 papers, just under half used only the baseline survey from the Study, with over one-third using linked data to morbidity, mortality or health services. Some used serial surveys from the Study to the follow up data (SEEF and W2) to assess self-reported disease incidence.

Just under half of the PA publications used a cross-sectional design to assess associations within the data or between spatial or geographic environmental factors and PA. Almost a third used longitudinal data to answer aetiological questions to determine physical activity exposure – health outcome or disease incidence relationships. The remainder examined health services usage, with or without disease outcomes.

Physical activity measures were equally divided across categories, with 29.7% reporting only sessions of activity, 18.7% reporting minutes of physical activity, and 35.2% reporting 'achievement of PA guidelines', although these guidelines varied between studies and over time (See Supplementary Table 1, available from: https://figshare.com/articles/journal_contribution/Supplementary_Table_1_details_of_included_studies_pdf/21514398). Around half of the studies used a large sample of more than 100 000 participants in the Study data (Table 1).

The prevalence of low PA levels, insufficiently active, not meeting guidelines or inactivity was estimated from the PA studies, and around a one-quarter of participants did not meet the PA guidelines used in the Study. This percentage was only 19% when the baseline whole sample was used. This means that at least three-quarters of Study participants were characterised as 'sufficiently active for health', which is much higher than the prevalence among the general population in Australia. Sitting time was reported in 11 studies but was the primary exposure variable in only four of them, three of which were cross-sectional analyses of the correlates of sitting time (Supplementary Table 1, available from: https://figshare.com/articles/journal_contribution/Supplementary_Table_1_details_of_included_studies_pdf/21514398). The results of the proportions 'low PA' were quite similar across quite different measures of PA.

Unsurprisingly, citation numbers were related to publication period (mean citations 88.2, 40.8 and 9.5 for the periods 2008–2014, 2014–2018, and 2019–2022, respectively, $p < 0.01$). Citation numbers were higher for aetiological cohorts (mean 59.9, standard deviation [SD] 114.7) than cross-sectional studies (39.1,SD 80.6) or health service cohorts (7.9, SD 7.1) or other designs, including methodological studies (32.0, SD 50.3), but the variation was large, and no differences were significant ($p = 0.34$). Adjustment for publication period showed an interaction between study type and citations ($p = 0.01$). The high variation in citations was due to a few papers, six of which had been cited more than 100 times, and a further 13 papers cited between 50 and 100 times. Of these 19 papers, 18 were published before 2018. The most cited papers described the cohort at baseline; answered aetiological questions regarding sitting time or the volume of vigorous PA associated with mortality risk; and examined associations between environmental attributes such as green space, PA and risk of incident diabetes or mental health problems. These highly cited papers and their contribution to physical activity research or preventive health are described in Supplementary Table 2, available from: https://figshare.com/articles/journal_contribution/supplementary_table_2_highly_cited_papers_pdf/21514401

Discussion

This review shows that PA measures or related research in the Study has been diverse, ranging from ecological correlates of being active to physical inactivity as a risk exposure for a wide range of conditions and other risk factors. The Sax Institute website estimates that the Study had generated around 480 peer-reviewed papers by Sep 2022[18], and if so, work that includes PA constitutes around one-sixth of the Study publications. The impact of these publications is evident in their citation numbers. They contribute to the evidence base for innovative health outcomes related to PA exposure, including dementia risk, eye health, the health benefits and risks of life stage transitions and the nuanced interaction between PA and obesity in diabetes risk (Supplementary Table 1, available from:https://figshare.com/articles/journal_contribution/Supplementary_Table_1_details_of_included_studies_pdf/21514398).

One important observation is that the Study participants are mostly physically active. Similar levels of PA are reported by gender[19] in contrast to other PA data. There is a less marked PA decline with older age observed in the Study sample than in other analyses, suggesting some healthy selection effects in those enrolled in the Study. Overall, only one-fifth of the the Study sample at baseline was low-active, not reaching the minimum WHO recommended threshold for health. These PA prevalence data can be compared with contemporary NSW Population Health Survey data, which collected representative sample data of NSW adults since 2004[20]. NSW Data continues to be expressed as the proportion not meeting the original 2004 PA guidelines, which were "5 sessions x 150 mins". Overall in 2010, 44.6% and in 2019, 38.3% of mid-aged and older NSW adults did not meet this threshold. NSW inactivity rates showed an age gradient, such that for those aged 75 years and older, 66% in 2010 and 2019 did not meet this threshold. These NSW representative data show a different distribution to the right-skewed Study prevalence data. This is a likely selection effect, as the Study had an 18% response rate. However, as this exposure still shows variation, it remains valid for epidemiological studies of disease causation.[21] This phenomenon of low response rates and high PA levels is not surprising, as it is seen in the large UK Biobank cohort. The effect of this right skew in the PA data, with the majority of the Study responders being at least 'sufficiently active', may potentially influence

associations in descriptive and cross-sectional analyses, especially when selected small sub-samples are studied. This suggests that the Study data may not be as suitable as more representative samples for population prevalence estimates or correlate studies.

Findings from many articles in the Study reinforce the benefits of PA for health. However, the high rates of PA among the Study participants may explain some unexpected findings in these PA studies, contrary to the literature on the topic. Unlike most other epidemiological studies, PA was not a clear independent risk factor for diabetes among the Study participants[22,23], nor did it show expected moderation of the relationship between obesity and diabetes risk[24] or between greenspace and obesity risk.[25] Similar unexpected findings were noted among Lebanese-born Australians, where PA was not associated with chronic disease risk[26] or in a pre-retirement sample, PA was not associated with subjective life expectancy.[27] These differences may be due to the restricted exposure to true inactivity among mostly active 45 and Up participants. This has implications for the policy utilisation of data from cohorts, and over-interpretation of any single exposure-outcome observation should be treated with caution.

The ways in which PA is measured and used across these studies varies widely compared to the standardised ways obesity, smoking or alcohol use rates are reported.[14] PA is reported as 'meeting guidelines', but also in minutes and sessions. To account for the right skew in these data, several studies used quartiles or tertiles of the PA distribution to assess dose-response relationships. However, this may underestimate true relationships if three of the four quartiles meet recommended PA levels. Part of the explanation is that the steepest gradient in the PA exposure–disease outcomes curve is noted in the most inactive groups.[28] Early papers from the Study reported that summed weekly PA sessions allowed better reconciliation across differently formatted versions of the study questionnaire and that total sessions showed good predictive value for meeting the 5x150 PA recommendations.[29].

Nonetheless, researchers and many reviewers prefer to use PA minutes with the 150 minutes threshold for sufficiently active as currently recommended by WHO.[1] This partly explains the disparate ways of reporting 'sufficient PA for health' in the Study. The variation in PA measures precludes comparison across studies. Future studies are encouraged to report the WHO minimum guideline of at least 150 minutes of moderate-vigorous PA so that sample estimates can be compared.

Another issue is the handling of missing data reported in only eight papers. Methods for assessing or imputing missing PA data require further consideration. Finally, concerning measurement, device-based assessment to validate a sample of the Study participants would be useful to corroborate the high rates of self-reported activity in this sample. Validation has occurred for self-reported obesity measures in this group[15], and biospecimens are being collected in subsamples for further physiological and genetic characterisation of this sample.[14] Thus, independent device-based PA measures, either with pedometers, accelerometers or even with tracking devices or smartphones, would enhance the validity of this highly active reporting sample.

Next, the study designs analysis suggests that more than half of these PA publications used a cross-sectional design, and this trend continues to the most recent period. While this may be useful for hypothesis generation, the Study's original intent was to investigate disease risk, causal factors and their association with linked data and health system outcomes. Furthermore, the citation analysis indicates the potential academic impact was substantially higher for aetiological cohort studies than other designs.

One difficult issue is that several papers reported similar questions to other published articles from the same or other research groups. The nuanced differences were often small, leading to some research overlap among papers. The increases in the number of PA papers using the Study does not necessarily contribute to their innovation or impact. However, permissions to use the cohort data and the high data access costs remain a challenge for prevention researchers and may explain the multiple publications emanating from a few better-resourced research groups.

More PA studies in the future should utilise the full potential of the Study (e.g., repeated measures, data linkages) to answer *a priori* unique and impactful research questions. For example, the most recent 2018–2020 wave of data collection is now available, and long-term PA patterns can be described and their relationship to subsequent health outcomes and mortality compared. This will provide a more nuanced usage of the PA behavioural pattern than just baseline data alone.

Study data was less commonly used for other research purposes. Only three studies assessed the moderator or mediator relationships of PA. One additional study was a case-control sub-study, and only one was an intervention (a protocol paper, shown in Supplementary Table 1, available from:https://figshare.com/articles/journal_contribution/Supplementary_Table_1_details_of_included_studies_pdf/21514398). Given the reasonably high reported activity levels of the Study participants, physical interventions may not be effective in this group, as ceiling levels are already reached. Innovative approaches to using the cohort to evaluate state- or national-level prevention programs or policies are not reported.

An earlier review of Study papers to 2017 investigated the extent to which the Study was used for causal epidemiological investigations and how it compared with other Australian cohorts.[30] To that date, the Study overall had been less used for aetiological analyses and policy evaluation than, for example, the Australian Longitudinal Study of Women. This finding persists in this updated examination of PA-specific papers, but given the lack

of any national policy or strategy on physical activity in Australia[31] through the Study period, there may not be sufficient policy initiatives to evaluate. Nonetheless, Australia produces a prolific volume of PA research, ranking second or third in the world for PA outputs.[31] This may further explain the high number of PA papers from the Study.

Conclusion

Physical activity-related research output has contributed substantially to the 45 and Up Study, as evidenced by the volume of publications and the number of highly cited papers. This research identifies new benefits of being active. Costs of hospital admissions and other health services utilisation seem lower among active participants from the Study compared to their inactive counterparts.[32,33] However, some areas could benefit from standardisation and coordination in this diverse field. Discussions around standardising the analysis of PA data and definitions of 'sufficiently active' would allow better comparison of the quantum of PA required for health between studies. Central coordination of publications is an administrative challenge in large cohorts. However, it could identify and reduce potential overlap among papers and reduce the volume of exploratory or hypothesis-generating research in this field. If Australia develops an integrated approach to PA and implements a national physical activity plan, large-scale cohorts such as the 45 and Up Study could play an important role in assessing changes attributable to such policy interventions.

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Externally peer reviewed, invited.

Competing interests

None declared.

Author contributions

All authors contributed to the development and revisions of the manuscript.

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