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# Bidirectional association between mental health and physical activity in older adults: Whitehall II prospective cohort study

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ABSTRACT

*Objective.* To investigate longitudinal and bidirectional associations between mental health and physical activity from midlife into old age.

*Methods.* Analysis was based on data from 6909 participants (aged 45 to 69 in 1997/99) from the Whitehall II cohort in the UK. Latent growth curve analysis examined possible bidirectional associations between the SF-36 Mental Component Summary and weekly physical activity measured at three time-points over ten years.

*Results.* Mental health and physical activity were associated at baseline ($\beta = 0.17$, 95% CI 0.13, 0.21) and associations persisted into old age. In the latent growth curve model, both mental health and physical activity increased and their rates of change 'moved together' over time ($\beta = 0.24$, 95% CI 0.11, 0.37). Relatively high baseline levels of either variable were associated with slightly slower increases in the other outcome ($\beta = -0.02$, 95% CI $-0.03$, $-0.01$; $\beta = -0.07$, 95% CI $-0.11$, $-0.13$), which are thought to reflect regression to the mean. However, those who started high on either variable remained the most advantaged at end of follow-up.

*Conclusions.* From midlife to old age, greater physical activity is associated with better mental health and vice versa. These findings suggest persistent longitudinal and bidirectional associations between physical activity and mental health.



## Introduction

The relationship between mental health and physical activity in older people is poorly understood. Observational studies tend to report positive cross-sectional associations which attenuate longitudinally (Almeida et al., 2006; Lee and Russell, 2003). Several reviews of intervention studies report small but significant improvements in mental health (Netz et al., 2005; Penedo and Dahn, 2005; Windle et al., 2010), but methodological shortcomings have meant that the effectiveness of physical activity for improving mental health cannot be determined (Lawlor and Hopker, 2001; Mead et al., 2009; Teychenne et al., 2008). Nonetheless, public health guidelines mention the mental health benefits of physical activity (World Health Organization, 2012) and advise that remaining physically active is of key importance for mental wellbeing (NICE, 2008).

At present, knowledge is not sufficient to infer a directional relationship. It is plausible that these phenomena influence each other over time, and understanding this sequencing is vital for understanding their association. Previous studies have modelled mental health and physical activity as outcomes in separate models. A recent study (Azevedo Da Silva et al., 2012) examined bidirectional associations during midlife (35 to 55 years at baseline). Cross-sectional analyses at three time-points over eight years suggested an inverse relationship between physical activity and depression and anxiety; however, lower physical activity at baseline did not predict symptoms eight years later. Higher cumulative physical activity was associated with lower symptoms at all time-points and cumulative exposure to depression and anxiety predicted reduced levels of physical activity. This approach does not capture whether change in one variable is associated with change in the other over time. Latent growth curve (LGC) analysis can describe interrelationships and potential causal pathways between variables over several time-points by integrating between-person differences in within-person change (Curran et al., 2010). LGC models allow all variables and their change over time to be modelled simultaneously while at the same time controlling for covariates and for change in the second outcome (Bollen and Curran, 2006). It has been shown that LGC models are typically characterised by higher levels of statistical power than traditional repeated-measures methods applied to the same data (Muthen and Curran, 1997). The aim of our study therefore was to extend Azevedo Da Silva and colleagues' study by a) examining associations

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from midlife to early old age and b) capturing initial levels and change over time in both variables simultaneously using an appropriate model.

## Method

### Participants

Data come from the Whitehall II cohort study, described elsewhere (Marmot et al., 1991). All civil servants aged 35 to 55 based in 20 Whitehall departments in London were invited to take part between 1985/88 and 73% (n = 10,308) provided written informed consent. The study was approved by the University College London ethics committee. Data were collected via a self-administered questionnaire containing information about health, work and lifestyle. The data used were drawn from 1997/99 (age 45 to 69; baseline for our analyses), 2002/04 (age 50 to 74) and 2007/09 (age 55 to 80) providing three repeated measures of physical activity and mental health, measured over ten years.

### Measures

*Physical activity*

Total weekly hours of physical activity were converted into standardised Metabolic Equivalent of Task (MET) values, which are multiples of the basal metabolic rate (Ainsworth et al., 2000). Moderate MET-hrs were calculated from the time spent on activities such as walking (METs 3–6) and vigorous MET-hrs were calculated from the time spent on activities such as sports or running (METs >6). MET-hrs in intensity categories were used to derive a binary variable for descriptive analysis according to whether WHO (2010) recommendations of at least 1 h of vigorous activity three times or 2.5 h of moderate activity five times per week were met (Sabia et al., 2009). Moderate and vigorous MET-hrs were also combined to create a continuous variable at baseline (M = 18; SD = 16.1). The range considered valid was 0 to 100 MET-hours/week, based on population-representative data from the 1998 Health Survey for England (National Centre for Social Research and University College London, 1998).

*Mental health*

*SF-36 Mental Component Summary (MCS)*. The Medical Outcomes Study 36-item short-form survey (SF-36) (Ware and Sherbourne, 1992) is a patient-reported measure able to distinguish physical from mental health (McHorney et al., 1993). Scores are continuous (range 0–100) and for descriptive analyses, participants were categorised as 'cases', i.e. having probable depression/dysthymia (MCS score of ≤42) and 'non-cases' (score of >42 points) (Ware et al., 1993).

*General Health Questionnaire (GHQ-30)*. The GHQ-30 (Goldberg, 1972) is a widely used screening instrument for common mental disorder symptoms. Scores range from 0 to 30 with a score of ≥5 indicating poor mental health (Stansfeld et al., 1997). The GHQ was used for sensitivity analyses.

*Covariates*

Covariates were drawn from the 1997/99 wave: age, gender, socioeconomic position, smoking status, alcohol consumption, fruit and vegetable consumption and presence of chronic disease. Socioeconomic position was measured by participants' last known employment grade. This three-level variable representing high (administrative), intermediate (professional or executive), and low (clerical or support) grades is a comprehensive marker of socioeconomic circumstances (Marmot et al., 1991). Participants were classified as 'non-drinkers' (0 units of alcohol/week), 'moderate drinkers' (1–14/21 units/week for women/men), or 'heavy drinkers' (>14/21 units/week for women/men) (Royal Colleges of Physicians, 1995). Smoking status was classified as current smoker, ex-smoker or never smoker. Frequency of fruit and vegetable consumption was recorded ranging from seldom or never to ≥2 times per day. Prevalent chronic disease was defined as physician-diagnosed cancer, coronary heart disease (CHD) including myocardial infarction, stroke (excluding transient ischaemic attack) or diabetes up to and including baseline and was dichotomised to indicate the presence or absence at baseline (1997/99). Diabetes and CHD were clinically verified (Alberti and Zimmet, 1998; Ferrie et al., 2006).

*Statistical analysis*

In descriptive analyses, we evaluated variables across physical activity and mental health categories. Differences between the groups were tested by chi-square for categorical variables and ANOVA for continuous variables. Provisional analyses considering each outcome separately explored potential effects of cumulative exposure to one variable on the outcome of the other at end of follow-up using linear regression.

Latent growth curve models allow participants with incomplete follow-up data to be included in the analysis by acknowledging that repeated measures on the same individual are correlated (Bollen and Curran, 2006). The maximum likelihood ratio (MLR) estimator allows for moderate non-normality in continuous outcomes. The intercepts represent initial status at baseline (1997/99) for each variable. The slopes represent change over time. Both are adjusted for covariates and fitted as random effects allowing each to vary between individuals. The equation has three parts. Where t = time score (0, 1 or 2), i = individual,/$\gamma$ = outcome, x = time score, $\eta_0$ = intercept, $\eta_1$ = slope, x/w = time invariant-covariate, $\alpha$ = factor loadings for the intercept, $\gamma$ = factor loadings for the slope, and $\varepsilon/\zeta$ = residuals: (1) $y_{ti} = \eta_{0i} + \eta_{1i}x_t + \varepsilon_{ti}$; (2) $\eta_{0i} = \alpha_0 + \gamma_0 w_i + \zeta_{0i}$; (3) $\eta_{1i} = \alpha_1 + \gamma_1 w_i + \zeta_{1i}$. In the structural equation modelling framework, equation (1) is the measurement part, defining factor loadings that determine the shape of the growth factors and equations (2, 3) are the structural part, determining regressions among latent variables and on covariates (Kline, 2011). The latent variable for the intercept represents initial status, the estimated value of the outcome at time score zero. The latent variable for the slope represents the expected linear increase in the outcome as the time score changes from zero to one, given that time scores are coded 0, 1, 2 (Bollen and Curran, 2006; Duncan and Duncan, 2004).

For the main analysis, we used multivariate (parallel process) LGC models (Bollen and Curran, 2006) to examine cross-sectional, longitudinal and bidirectional associations between two growth processes simultaneously: mental health and physical activity. The regressions of the physical activity slope on the mental health intercept and the regression of the mental health slope on the physical activity intercept represent bidirectional effects (if the starting point of one predicts change in the other). The correlation between intercepts represents the estimated correlation at baseline. The correlation between slopes represents a bidirectional effect (both variables 'moving together' over time). The main advantage of this approach is that correlations between the starting point and change in two outcomes are modelled simultaneously.

Several sensitivity analyses were conducted. First, GHQ-30 summary scores were substituted in place of the continuous MCS score in order to establish whether choice of mental health measure impacted results. Second, a binary physical activity variable (meeting recommendation/not) was used in place of continuous MET-hrs to establish whether classifying physical activity as dichotomous impacted results. Third, the model was run on a nested sample of participants with complete data at all waves to evaluate possible bias from dropout.

## Results

The analytic sample size available was 6909 participants (4883 men), with data on all covariates at baseline and on physical activity or mental health data at least once over follow-up. Of the analytic sample, 74.6% and 78.5% had all three waves and 89% and 90.9% had at least two waves of respective mental health and physical activity data available. Compared with the Whitehall II study population at recruitment, those included were slightly younger (mean 44.3 v. 44.7 years in 1984–1988, p = 0.05), more likely to be men (59.0 vs. 70.7%, $p < 0.001$), more likely to be white (92.5 v. 84.8%, $p < 0.001$) and were less likely to be at a low/clerical employment grade (35.8 v. 16.3%, $p < 0.001$).

Table 1 provides descriptive statistics for this sample according to activity levels (meeting WHO recommendation/not) and mental health 'caseness' (probable depression/not). Those who met the recommendation were significantly more likely to be older, white, married, men, heavy drinkers, consume two or more fruits or vegetables per day and have a higher employment grade (all $p < 0.001$). People who did not meet recommendations were more likely to be MCS cases. MCS cases were more likely to be younger, ethnic minority background, women, smokers, and have chronic disease and a low employment grade. They were less likely to be married, consume two or more fruits or vegetables per day and to meet the WHO recommendations for physical activity (all $p < 0.001$).

The mean SF-36 MCS scores were 50.9 (SD 9.5), 52.3 (SD 8.9) and 53.6 (SD 8.2) in 1997/99, 2002/04 and 2007/09, respectively and the proportion of probable depression/dysthymia cases decreased over follow-up from 15.1 and 10.7 to 8.0%. The mean moderate/vigorous

**Table 1**
Baseline characteristics according to WHO physical activity status and a SF-36 MCS depression/dysthymia status.

| | Total ($n = 6909$) | Did not meet WHO recommendation 76.6% ($n = 5262$) | Met WHO recommendation 23.3% ($n = 1613$) | MCS case/'poor' mental health 15.1% ($n = 1041$) | MCS non-case/'good' mental health 80.6% ($n = 5571$) |
|---|---|---|---|---|---|
| *Demographics* | | | | | |
| Mean age (SD) | 55.1 (6.3) | 55.5 (6.1) | 57.1 (5.9)* | 54.2 (5.7) | 56.2 (6.0)** |
| % Men (n) | 70.7 (4883) | 67.7 (3563) | 80.2 (1294)** | 63.3 (659) | 72.9 (4064)** |
| % White (n) | 92.4 (6385) | 91.4 (4806) | 96.1 (1549)** | 90.2 (939) | 93.3 (5198)** |
| % Married or co-habiting (n) | 76.8 (5218) | 75.0 (3870) | 82.8 (1320)** | 67.6 (690) | 78.9 (4339)** |
| % Low employment grade (n) | 13.3 (920) | 15.5 (814) | 6.3 (102)** | 17.8 (185) | 11.4 (637)** |
| % Current smoker (n) | 10.6 (730) | 11.7 (616) | 6.8 (110)** | 14.5 (151) | 9.7 (543)** |
| % Heavy drinker (n) [a] | 24.0 (1658) | 23.3 (1228) | 26.6 (429)** | 25.6 (267) | 24.3 (1351) |
| % Chronic disease (n) [b] | 25.2 (1742) | 25.8 (1358) | 23.3 (376) | 30.3 (314) | 23.8 (1327)** |
| % MCS case (n) | 15.1 (1041) | 16.5 (868) | 10.4 (168)** | – | – |
| % Met WHO recommendation | 23.2 (1613) | – | – | 16.1 (168) | 25.0 (1391)** |
| % fruit/veg twice per day | 38.0 (2625) | 35.4 (1865) | 46.6 (751)** | 33.4 (348) | 39.4 (2193)** |

[a] One alcohol unit corresponds to 8 g of alcohol. Heavy drinker denotes >14 units/week for women and >21 units/week for men.
[b] Chronic disease was defined as self-reported cancer, CHD, stroke or diabetes up to and including baseline.
* Denotes significant group difference at $p < 0.05$ level.
** Denotes significance at $p < 0.01$.

MET-hrs per week of physical activity were 16.0 (SD 15.3), 17.7 (SD 15.6) and 17.6 (SD 16.0) at the three time-points and the proportions of those meeting the WHO recommendations were 23.3, 24.6 and 23.8% respectively.

Provisional analyses considering each outcome separately using linear regression demonstrated that cumulative exposure to higher levels of physical activity (the mean moderate/vigorous MET-hrs over ten years) was associated with better mental health at end of follow-up. Specifically, every MET-hr increase in cumulative physical activity was associated with a half-point increase in MCS score ($\beta = 0.05$, 95% CI 0.03, 0.06), controlling for baseline MCS, age, gender, grade and chronic disease. Conversely, a cumulative score representing mean mental health across follow-up was associated with more physical activity at end of follow-up. For every one point MCS increase, physical activity increased by 0.09 MET-hrs. ($\beta = 0.09$, 95% CI 0.04, 0.14), controlling for baseline physical activity and covariates.

Fig. 1 shows the physical activity and mental health trajectories, of observed available data at each time-point. Fig. 1A shows the physical activity trajectory according to MCS caseness at baseline. Those with probable depression/dysthymia did less physical activity than those without. These differences persisted across follow-up, but narrowed over time. Fig. 1B shows the trajectory of MCS score according to whether participants met WHO recommendations for physical activity at baseline. Those who did had better mental health at baseline and across follow-up, but differences also narrowed over time. Although those with good mental health decreased activity over time and those with high levels of physical activity showed slower increases to mental health, differences persisted and both groups were always in a relatively better position from baseline to end of follow-up. These figures illustrate the expected change for each variable based only on the initial status of the predictor variable, ignoring information on repeated measures of the predictor. In contrast, the multivariate LGC model incorporates all three measures for both variables.

## Main results

Results from the multivariate LGC model are shown in Fig. 2. The model had a good fit to the data (CFI = 0.99, TLI = 0.97, RMSEA = 0.03, SRMR = 0.01) (Hu and Bentler, 1999). In the model, both variables were treated as continuous to avoid loss of information and statistical power. Coefficients are estimated for male participants aged 55 with intermediate employment grades. The intercept (estimated baseline value) for physical activity was 17.42 (95% CI 15.19, 19.64) which refers to the expected number of min/week at baseline for a participant with these covariate values. The slope (change over time) for physical activity was 3.69 (95% CI 1.25, 6.13) indicating a small increase per study wave. The intercept for mental health was 51.10 (95% CI 49.37, 52.82) which refers to the expected MCS score at baseline. The slope

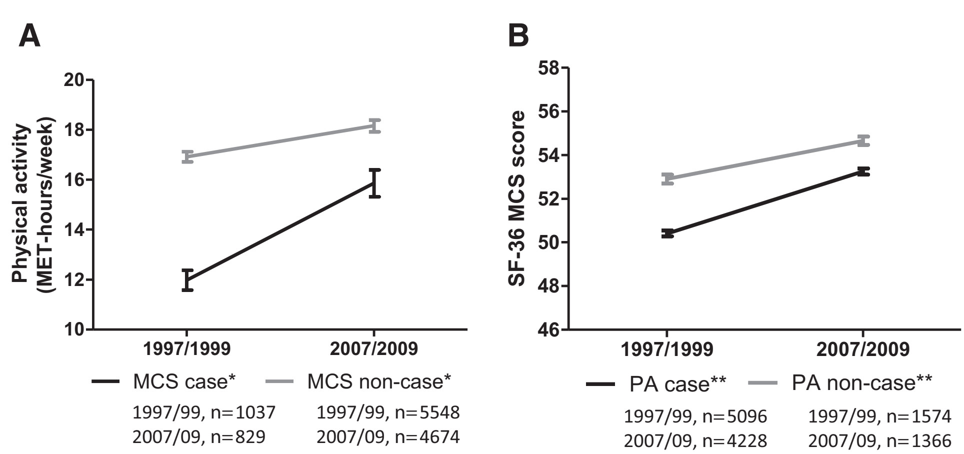


**Fig. 1.** Change in physical activity by baseline SF-36 MCS case status (A) and change in SF-36 MCS by baseline physical activity status (B) over 10 year follow-up. *SF-36 mental component score 'caseness' defined as ≤42 indicating probable depression and/or dysthymia at baseline (1997/99); **Physical activity 'caseness' defined as not meeting WHO recommendations for physical activity at baseline (1997/99). Figures are based on available data at each time-point. Standard error of the mean (SEM) is shown in error bars on each trajectory.

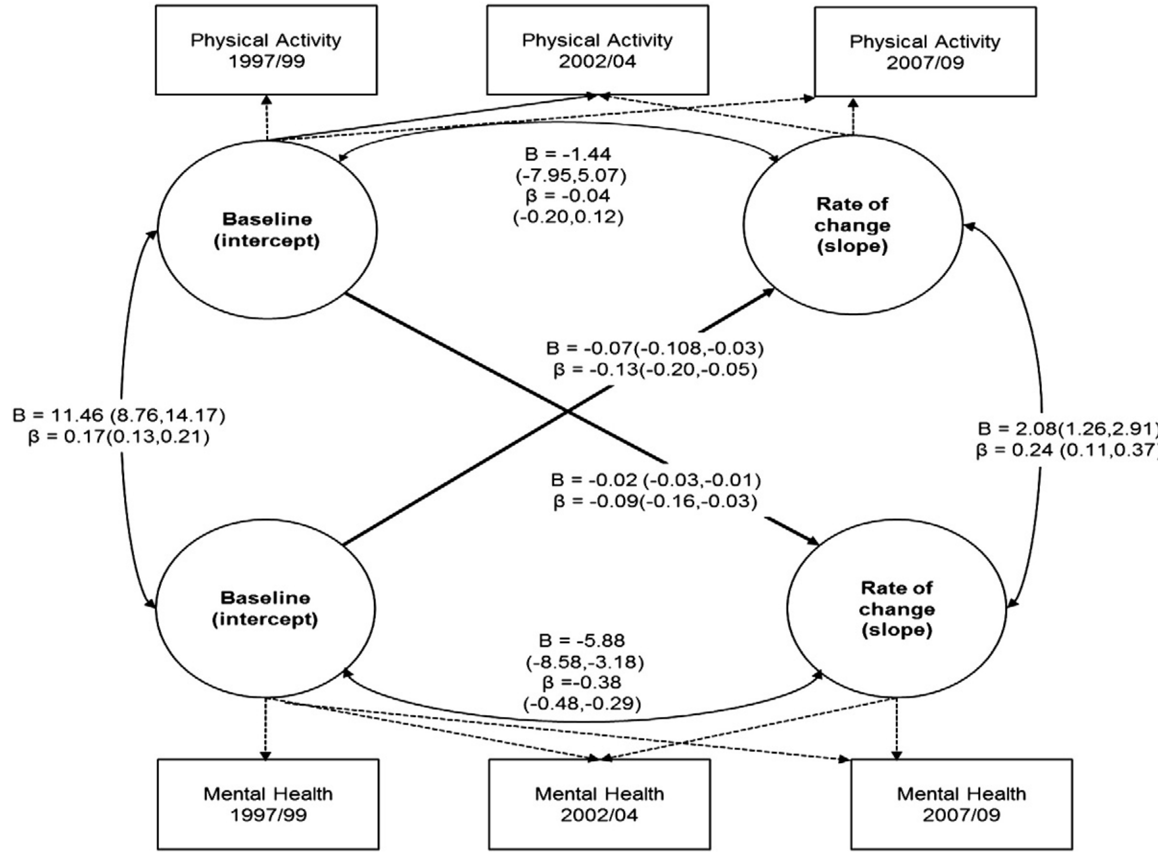


**Fig. 2.** Results from the multivariate latent growth curve model. Single-headed arrows (β) represent unstandardised regression coefficients and show the change in the outcome variable per unit change in the predictor variable. Double-headed arrows (β) represent standardised beta coefficients that are broadly equivalent to the correlation between behaviours at baseline (correlated intercepts), and the correlation between the rate of change in each behaviour over time (correlated slopes). To facilitate interpretation only the latent variables (intercept and slope) are shown. Intercepts and slopes were also regressed on covariates though this is not shown in the model. Coefficients are also shown in Table 2.

of 1.58 (95% CI 0.68, 2.53) indicated that MCS would be expected to increase by 1.58 points per study phase.

The intercepts were positively correlated — higher levels of physical activity at baseline were associated with better mental health at baseline ($\beta = 0.17$, 95% CI 0.13, 0.21). The slopes were also positively correlated ($\beta = 0.24$, 95% CI 0.11, 0.37) indicating that over time as physical activity increased, so did mental health and at a similar rate. The variables 'moved together' over time. Higher mental health at baseline was associated with slightly slower increases in physical activity over follow-up ($\beta = -0.07$, 95% CI −0.11, −0.03). This means that differences between participants' level of physical activity according to mental health narrowed, partly reflecting regression to the mean (those who start high tend to move closer to the mean). Similarly, higher physical activity at baseline was associated with slightly slower increases to mental health ($\beta = -0.02$, 95% CI −0.03, −0.01). Several of the covariates were associated with both variables (see Table 2).

Results from the sensitivity analyses using the GHQ-30 as a measure of mental health did not materially impact conclusions, suggesting that the associations were not specific to the measure. Results from the models based on participants with all data were also comparable, indicating that results were not driven by non-random dropout. Associations were not found when categorising physical activity or MCS as

**Table 2**
Growth curve model coefficients (unstandardised) for regression of intercepts and slopes of mental health and physical activity on covariates at baseline and 95% confidence intervals. Note. Mental health is measured by SF-36 MCS score (treated as continuous). Physical activity is measured by MET-hours of moderate/vigorous activity (treated as continuous). Age is centred at 55, socio-economic status at the middle employment grade.

| | Slope of mental health | | Intercept of mental health | | Slope of physical activity | | Intercept of physical activity | |
|---|---|---|---|---|---|---|---|---|
| Covariate | B | 95% CI | B | 95% CI | B | 95% CI | B | 95% CI |
| Age | −0.11 | −0.13, −0.09 | 0.38 | 0.35, 0.42 | −0.17 | −0.21, −0.13 | 0.37 | 0.31, 0.42 |
| Female | 0.35 | 0.01, 0.65 | 0.88 | 0.42, 1.34 | −1.37 | −1.94, −0.81 | −5.79 | −6.56, −5.03 |
| Chronic disease | 0.26 | −0.03, 0.55 | −1.31 | −1.82, −0.80 | −0.26 | −0.72, 0.20 | −1.69 | −2.44, −0.94 |
| Lower employment grade | −0.04 | −0.25, 0.16 | −0.34 | −0.70, 0.03 | 0.20 | −0.13, 0.52 | −2.09 | −2.62, −1.55 |
| Current smoker | −0.01 | −0.20, 0.18 | −0.22 | −0.57, 0.12 | 0.34 | 0.02, 0.66 | −0.27 | −0.77, 0.22 |
| Heavy alcohol (vs. moderate) | −0.13 | −0.41, 0.15 | −0.23 | −0.80, 0.24 | −0.35 | −0.85, 0.16 | 0.57 | −0.28, 1.41 |
| Fruit/veg consumption | −0.06 | −0.17, 0.05 | 0.67 | 0.47, 0.86 | −0.07 | −0.23, 0.10 | 1.61 | 1.37, 1.85 |
| Married/co-habiting | 0.08 | −0.25, 0.40 | −1.76 | −2.32, −1.18 | −0.51 | −1.00, −0.03 | −2.02 | −2.80, −1.25 |
| Intercept | 17.42 | 15.19, 19.64 | 3.69 | 1.25, 6.13 | 51.10 | 49.37, 52.82 | 1.58 | 0.63, 2.53 |

binary outcomes. This could suggest either a loss of statistical power or reflect differences in the estimators used in the continuous versus categorical models.

## Discussion

In this study of 6909 adults observed three times over ten years, we found significant associations between physical activity and mental health at baseline which persisted into early old age. Physical activity increased and mental health improved over time and those with faster increases or improvements also tended to experience corresponding change in the other outcome. The moderate baseline associations narrowed over time (partly reflecting regression to the mean for those starting relatively high on either variable) but persisted to the end of follow-up. Physical activity and mental health appear to have a longitudinal and bidirectional association from midlife to early old-age.

This study has several limitations. The cohort comprised white-collar workers and therefore results do not generalise to manual occupations or the unemployed, however the cohort did include the lowest employment grades and those with no formal qualifications. Whitehall II also demonstrates some evidence of health selection including lower mortality rate compared with the UK population and women are under-represented (Wills et al., 2011). Self-reported physical activity is well-known to overestimate actual activity levels (National Centre for Social Research and University College London, 2009) and this is likely to have led to underestimated effects, though this is unlikely to vary as a function of mental health. There are also conceptual issues with measuring mental health, however both the SF-36 and GHQ-30 are valid and reliable instruments that measure different conceptions of mental health (McCabe et al., 1996).

A particular strength of the study is the use of LGC modelling to examine these associations because the model allows both variables to act as predictor and outcome variables while controlling for other growth processes and missing data (Curran et al., 2010). This provides a clearer understanding of the relationship between change in mental health and physical activity over ten years. Related studies of prospective cohort samples have also examined the temporal relationship between variables over several waves of data using this approach and reported bidirectional effects between smoking and alcohol use (Hagger-Johnson et al., 2013), depression and substance use in adolescents (McKowen et al., 2013) and depression and obesity (Konttinen et al., 2014).

To our knowledge, this is one of very few studies to examine the potential for bidirectional effects of physical activity and mental health over time in older people from a well-defined Western sample. The findings add to Azevedo Da Silva et al. (2012) work from the same cohort in which the relationship between physical activity and depression/anxiety was found to be bidirectional over a period of eight years in early to midlife according to two separate logistic regressions. However, our findings differ because they extend into old age and because both outcomes and their rates of change were explored in one model, providing a more accurate picture of a reciprocal relationship. The results partly contrast with those of Ku and colleagues' recent LGC modelling of a Taiwanese cohort of older adults (2012) who report that high levels of baseline physical activity were associated with slower increases in depressive symptoms, but not the reverse. This may be due to differing methodologies — they used another measure of mental health, an older, non-western sample, and symptoms increased over follow-up. In the current cohort, mental health demonstrated a positive trajectory. Yet, both studies' findings echo population norms for mental health; an increase throughout middle and into old age followed by a slow decrease after the age of 75 (Blay, 2007; Jorm, 2000).

Given that the association between physical activity and mental health was already established at baseline, future studies with younger cohorts, longer follow-up are needed to investigate the long-term impact of regular and cumulative physical activity on mental health and the reverse. In addition, there may be shared common influences which we did not consider, e.g. genetic factors or early life exposures that are antecedent to physical activity and mental health trajectories across the life course.

Initial levels of physical activity were negatively associated with mental health trajectory over time, and vice versa. However, these trajectories (both becoming more favourable across follow-up) were positively associated suggesting that older people with higher physical activity levels start off with better mental health, and that people with better mental health engage in more physical activity at baseline and that the association is attenuated over time. However, differences remain. The positive association between the change in both phenomena over time, as well as the finding that cumulatively good mental health and cumulative exposure to physical activity predicted favourable outcomes to the other variable, highlights the possibility that neither has a 'causal' impact on the other; rather both may share a common underlying factor. If there is a temporal sequence between mental health and physical activity, it may predate middle/old age. Factors which may moderate and mediate the relationship should therefore be investigated.

### Conflict of interest statement

The authors declare no conflicts of interest including any financial, personal or other relationships with other people or organizations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, their work.

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Siri Steinmo and Gareth Hagger-Johnson performed the data analysis and all authors contributed to the interpretation of the data. Siri Steinmo wrote the first draft of the paper. All authors contributed to successive drafts of the paper and gave final approval for submission. Siri Steinmo and Gareth Hagger-Johnson had full access to all the data and take full responsibility for the integrity of the data and the accuracy of the analysis.

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