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The relationship between physical and mental health: A mediation analysis

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ABSTRACT

There is a strong link between mental health and physical health, but little is known about the pathways from one to the other. We analyse the direct and indirect effects of past mental health on present physical health and past physical health on present mental health using lifestyle choices and social capital in a mediation framework. We use data on 10,693 individuals aged 50 years and over from six waves (2002–2012) of the English Longitudinal Study of Ageing. Mental health is measured by the Centre for Epidemiological Studies Depression Scale (CES) and physical health by the Activities of Daily Living (ADL). We find significant direct and indirect effects for both forms of health, with indirect effects explaining 10% of the effect of past mental health on physical health and 8% of the effect of past physical health on mental health. Physical activity is the largest contributor to the indirect effects. There are stronger indirect effects for males in mental health (9.9%) and for older age groups in mental health (13.6%) and in physical health (12.6%). Health policies aiming at changing physical and mental health need to consider not only the direct cross-effects but also the indirect cross-effects between mental health and physical health.

1. Introduction

The prevalence of common mental disorders is on the rise among the populations of western industrial nations (Twenge et al., 2010; Hidaka, 2012). A strong link has been found between mental and physical health (Nabi et al., 2008; Surtees et al., 2008). Ohrnberger, Fichera and Sutton (2017) find strong cross-effects between physical and mental health even after controlling for confounders. However, little is known about the potential pathways through which mental health affects physical health and vice versa (i.e. so-called "indirect effects"). Understanding these indirect effects, and how they vary between population groups, could have important implications for the design of health policies.

The aim of this paper is to fill this gap by proposing a mediation framework and estimating the mediating effects of lifestyle choices and social capital in the relationships between physical and mental health in the older population. The analysis is nested within the health economic framework of health production and consumption. It focuses on lifestyle factors and social capital as they are core input factors in health and relevant to health policies for older people (Artaud et al., 2013; Holt-Lunstad et al., 2012). A report by the Ageing Research Group (Melzer et al., 2012) finds that approximately 55% of the burden of disease amongst the population aged 60 years and over is avoidable by changes in lifestyles in high income countries. On the full population, lifestyle factors explain up to 70% of the burden of disease (WHO, 2009). Social capital includes factors such as social isolation, loneliness and exclusion. These are strong risk factors for ill health and impose a high risk on the health of older populations that could be easily avoided with low-cost interventions (Steptoe et al., 2012).

We estimate the total effects, composed of the indirect and direct effects, of past mental health on physical health and of past physical health on mental health among the older English population. We use six waves of data from the English Longitudinal Study of Aging (ELSA, 2002–2012). For the direct effect estimations, we model the present level of one form of health as a function of the stock of the other form of health, following Ohrnberger et al. (2017). The indirect effects are modelled using individuals' lifestyle choices (physical activity and cigarette consumption) and social capital (social interaction). We then calculate total differentials, which are marginal changes of a function of variables conditional on marginal changes in another variable in a multivariate regression framework, to estimate the direct, indirect and total effects. This is similar to the product of coefficients method (Baron and Kenny, 1986; MacKinnon et al., 2007).

Many psychological, epidemiologic, and economic studies have used mediation analysis, but none in the context of the relationship between physical and mental health and the pathways that we consider. A group of these studies has analysed direct and indirect effects of anxiety and childhood traumas on mental health (Turner and Butler,

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2003; Dour et al., 2014). A second group of studies has investigated the mediating effect of mental health on quality of life and labour outcomes (Wong et al., 2010; Johar and Truong, 2014). A third group of studies has analysed the mediating role of health investments on labour outcomes and quality of life (Han et al., 2011; Wicke et al., 2014; Bekele et al., 2015 Burns et al., 2015).

To preface our results, we find that both present physical and mental health are explained by direct and indirect effects of past mental and physical health, respectively. The indirect effect accounts for about 10% of the total effect in both models, mainly explained by past physical activity. Estimation by subgroups shows heterogeneous effects by age and gender. The findings are robust to the timing of the mediators and how the stock of addiction is modelled.

2. Conceptual framework and mediation analysis

2.1. Conceptual framework

Grossman (1972) considered health as part of human capital, from which individuals gain both consumption and production benefits. Healthy time is needed to enjoy leisure activities and provides direct utility, like a consumption good. Healthy time is also an input to production of income. Health itself is produced by using medical care and can be consumed or produced by lifestyle choices (Grossman, 1972). Theoretical contributions since Grossman have added other determinants of health such as the decision to retire, early childhood investments and endowments, stress, social capital and socio-economic status (Bolin et al., 2003; Galama, and van Kippersluis, 2013).

We adapt this economic framework to the study of two components of health capital, physical and mental health. To do so, we hypothesise several channels through which physical and mental health may impact upon each other, drawing on theoretical and empirical evidence from the economic, medical and epidemiological literature. We graphically represent these pathways in Fig. 1.

First, physical and mental health may impact upon each other via employment. Worse physical (or mental) health may imply a loss of wages or productivity reducing access to healthier foods and environments. This income effect impacts negatively on mental (or physical) health. Similar negative health effects may also be induced by lack of sleep or stress at work associated with having a mental (or physical) health condition (Contoyannis and Rice, 2001; García-Gómez et al., 2013).

Second, mental health may affect individuals' decision making process, impairing their ability to access information on their health, on prevention, and on the quality of healthcare providers, and thus impacting on their physical health (Mani et al., 2013).

Third, physical and mental health are associated with lifestyle choices such as physical activity, smoking and alcohol consumption and diet (Stampfer et al., 2005; WHO, 2009). Several studies have found that physical activity is negatively associated with depression/anxiety disorders and poor physical health outcomes (Gerber and Puehse 2009; De Mello et al., 2013; Durstine et al., 2013; Wang et al., 2014; Hegberg and Tone, 2015). Systematic reviews find strong evidence for positive effects of exercising on both mental and physical health outcomes for older people (Forbes et al., 2008; Clegg et al., 2012). A reverse-causal relationship is likely to occur as individuals with better physical and mental health are also more likely to exercise. A systematic review on the smoking cessation and mental health by Taylor et al. (2014) finds general evidence for reduced depression, anxiety, and stress after smoking cessation interventions. Reverse-causality is likely to occur as smoking rates are twice as high among adults with depression or anxiety disorders (RCP, 2013).

Moderate alcohol consumption has been found to have a positive relationship with both mental and physical health, and better mental health and better physical health have been found to predict moderate drinking (Stampfer et al., 2005; Lang et al., 2007). Excessive drinking and abstention show negative effects on health outcomes and are predicted by worse physical and mental health (Rehm et al., 2010; Frisher et al., 2015). Dietary choices are another important lifestyle factor in the health production function. A low-quality diet is associated with higher mortality risk (Haveman-Nies et al. 2003). Mujcic and Oswald (2016) find a strong and positive association of increased fruit consumption with increased wellbeing and happiness.

Finally, social interactions are critical production factors in health. Previous studies have found a strong positive relationship between social interaction and mental health (Dour et al., 2014; Bekele et al., 2015). Loneliness and social isolation have both been found to be associated with increased mortality risk, whilst controlling for baseline mental and physical health (Steptoe et al., 2012). Holt-Lunstad et al's. (2012) systematic review shows a consistent effect of social

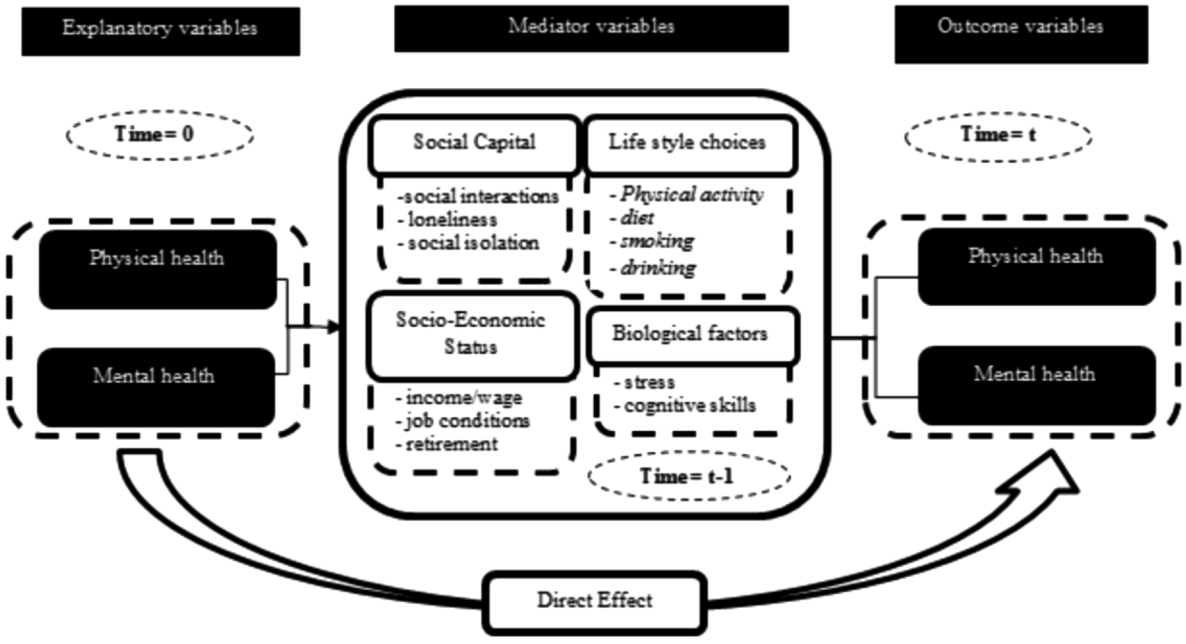

Fig. 1. The direct and indirect effects between physical and mental health.

relationships on decreased mortality risk. Reverse-causal pathways have also been established in the literature, with physical disability and poor mental health causing more isolation (Steptoe et al., 2012).

2.2. Application to mediation analysis

We draw on this conceptual framework to motivate our mediation analysis. Whilst we recognise the channels through which mental and physical health impact on each other are many and varied, our approach considers physical activity, smoking and social interactions as the main mediating factors for the following reasons. Firstly, these mediators are important predictors of mortality. Smoking is the leading cause of preventable death in the UK (Office for National Statistics UK, 2016). Tobacco use explains 17.9% of all deaths and physical inactivity explains 7.7% of all deaths (WHO, 2009). Social capital is similarly important in increasing the risks of social isolation, loneliness and exclusion of older populations, which lead to higher risks of mortality (Holt-Lunstad et al., 2012; Melzer et al., 2012; Steptoe et al., 2012). Other potential mediators are less important for mortality. For example, alcohol consumption and dietary choices together explain only 4.1% of deaths (WHO, 2009).

Secondly, other potential mediators such as stress and sleep are captured directly by our measure of mental health. Thirdly, other factors such as obesity, high blood pressure and alcohol consumption are widely used in the literature as health outcome measures (Banks et al., 2006). Using ELSA, Holdsworth et al. (2016) find that alcohol consumption is more an indicator of good mental and physical health than an input factor into health. Fourthly, the employment channel is less important in the older population as 59% of our sample is retired. Finally, we have concerns over the measurement of other mediators in our dataset. For example, the ELSA started including questions about dietary choices only in the third wave and the phrasing of these questions changed from wave 5 onwards.

For these reasons, we consider our estimates to be lower bounds of the indirect effects between physical and mental health and upper bounds of their direct effects.

3. Data and summary statistics

3.1. The English Longitudinal Study of Ageing (ELSA)

The ELSA is an ongoing longitudinal survey which started in 2002 (Marmot et al., 2017). We use six waves from 2002 to 2012. The data are collected in interviews once every two years. The study is a representative sample of English population aged 50 years and older, collecting objective and subjective data on physical and mental health, and on socio-economic status. The first wave was conducted between March 2002 and March 2003 and consisted of 11,304 individuals. The sample was refreshed in wave 3 (2006/2007), wave 4 (2008/2009) and in wave 6 (2012/2013) to maintain the original sample size.

3.1.1. Explanatory and outcome variables

We measure physical health using the six-item version of activities of daily living (ADL) developed by Katz et al. (1963). The ADL index measures difficulties in performing tasks required for personal self-care and independent living in every-day life (see online appendix). The ADL index ranges from 0 (most difficulties and worst physical health) to 6 (least difficulties and best physical health).

We measure mental health using the validated eight-item version of the Center for Epidemiological Studies-Depression (CES-D) developed by Radloff (1977). CES-D is a self-assessed depression screening test. The CES-D scale ranges from 0 implying high depression and worst mental health to 8 implying no depression and best mental health (see online appendix).

3.1.2. Mediators

We use a social interaction index as a measure for health investments related to social capital. The social interaction index is constructed by summing over the frequency of interactions with friends, family and children (3 = at least once a week; 2 = once or twice a month; 1 = every few months, once or twice a year; and 0 = less than once a year or never), and a binary variable which takes a value of one if the individual is in a relationship. The maximum value is 10, indicating strongest possible social interactions. The lowest value is 0, indicating lowest possible social interactions. The measure is similar to Steptoe et al. (2012) and also reflects changes in social isolation and loneliness.

We include physical activity and cigarette consumption as measures of lifestyle choices. Physical activity (PA) is measured on a four-level ordinal scale (0 = no PA, 1 = mild PA, 2 = Moderate PA, 3 = Vigorous PA). Cigarette consumption is defined as the number of cigarettes smoked daily with a value of zero for non-smokers.

3.1.3. Control variables

As demographic characteristics, we include gender, age, age-squared, white ethnicity, the number of household members, and whether the individual has a higher educational qualification. We also include the following measures: retired from paid work, covered by supplementary private health insurance, and log-yearly equivalised disposable real household income deflated using the Consumer Price Index with baseline 2005 = 100. We also control for the geographical region of residence (North, South, East and Midlands, London).

3.2. Summary statistics

The full sample size for all years is 10,693. Approximately 59% of the sample are retired, 45% are males, 59% have higher education qualifications, and the majority is from a white ethnic group (Table 1). Few respondents have supplementary private health insurance and the average exponential log yearly disposable equivalised real income is £13,360. The modal respondent is in good present physical health and in moderate to good present mental health. He/she reports good baseline physical health, moderate to good baseline mental health, smokes little or not at all, is moderately physically active, is moderately socially interactive, and lives together with another person at his/her household. The sample split by waves shows respondents' average physical health and mental health are stable over time. The number of cigarettes smoked per day decreases over time. Physical activity and social interaction remain relatively constant over time.

4. Methodology and empirical strategy

We estimate the following reduced-form models for physical and mental health:

$$P_{it} = \beta_0 + \beta_1 P_{it=0} + \beta_2 M_{it=0} + L_{it-1}\beta_3 + \beta_4 C_{it-1} + \mathbf{X_{it}}\beta_5 + v_{it} \quad (1)$$

$$M_{it} = \beta_0 + \beta_1 P_{it=0} + \beta_2 M_{it=0} + L_{it-1}\beta_3 + \beta_4 C_{it-1} + \mathbf{X_{it}}\beta_5 + P_{it} \quad (2)$$

with P_{it} as the physical health of individual i at time t, explained by physical health at baseline $P_{it=0}$, mental health at baseline $M_{it=0}$, a vector of L lifestyle choices at t-1, social interaction (C) at t-1, a vector of X covariates at time t for individual i and an idiosyncratic error component v_{it}. The specification is similar for mental health M_{it}.

We use the lagged values of lifestyle choices and social interaction for three reasons. Firstly, health investments produce health in the following periods (Grossman, 1972). Secondly, changes in mental and physical health due to changes in health investments take time to materialise (see Kim et al., 2012; Will et al., 2001 for cigarette consumption; Mansikkamäki et al., 2015 for physical activity; and Forsman et al., 2011; Umberson and Montez, 2010 for social interactions). Thirdly, by modelling the sequence of events we mitigate concerns over

Table 1
Descriptive statistics.

Variables	Definition	2004 n = 6147	2006 n = 5423	2008 n = 5283	2010 n = 6601	2012 n = 6491
ADL	0-6 scale; with 0 = worst physical health and 6 = best physical health	5.62 (0.95)	5.64 (0.93)	5.68 (0.84)	5.69 (0.86)	5.69 (0.87)
CES	lagged CES: 0–8 scale; with 0 = worst mental health and 8 = best mental health	6.38 (2.02)	6.61 (1.88)	6.71 (1.83)	6.61 (1.86)	6.79 (1.77)
Baseline ADL	Baseline ADL	5.66 (0.88)	5.69 (0.84)	5.74 (0.76)	5.76 (0.73)	5.77 (0.72)
Baseline CES	Baseline CES	6.57 (1.88)	6.61 (1.84)	6.67 (1.82)	6.70 (1.81)	6.69 (1.83)
Lagged Physical Activity	0 = no PA, 1 = mild PA, 2 = Moderate PA, 3 = Vigorous PA	2.03 (0.86)	2.06 (0.82)	2.08 (0.80)	2.06 (0.84)	2.06 (0.83)
Lagged Cigarettes	Number of cigarettes smoked daily, 0 for non-smokers	1.77 (5.29)	1.50 (4.87)	1.41 (4.78)	1.28 (4.49)	1.13 (4.17)
Lagged Social Interaction	0 = lowest social interaction; 10 = highest social interaction	6.71 (2.14)	6.63 (2.12)	6.65 (2.10)	6.63 (2.10)	6.57 (2.11)
Male	1 if male, 0 if female	0.45	0.45	0.45	0.45	0.45
White	1 if white, 0 otherwise	0.98	0.98	0.98	0.98	0.98
Age	Age of the respondent	66.26 (9.60)	67.21 (9.40)	66.88 (9.67)	67.03 (9.00)	68.26 (8.70)
Higher Education	1 if higher education (university +), 0 otherwise	0.53	0.56	0.60	0.62	0.63
Household Size	Number of household members including respondent	1.92 (0.76)	1.92 (0.76)	1.94 (0.77)	1.95 (0.75)	1.93 (0.74)
Private Insurance	1 if has supplementary private health insurance, 0 otherwise	0.16	0.16	0.16	0.15	0.13
Retired	1 if retired from work, 0 otherwise	0.55	0.58	0.58	0.60	0.65
North	1 if resident in northern England, 0 otherwise	0.31	0.31	0.29	0.28	0.29
South	1 if from southern England, 0 otherwise	0.28	0.29	0.29	0.29	0.29
East and Midlands	1 if from East and/or Midlands, 0 otherwise	0.33	0.32	0.34	0.35	0.34
London	1 if from London, 0 otherwise	0.08	0.08	0.09	0.07	0.08
Log-equivalised household income	Yearly log-equivalised real household income in GBP	9.44 (0.65)	9.46 (0.66)	9.51 (0.70)	9.53 (0.64)	9.55 (0.63)

Note: Descriptive statistics are provided for the estimation sample. n indicates the number of individuals. Variable means with standard errors in parentheses.

potential reverse causality between physical and mental health. We assume that, conditional on baseline health, lifestyle choices and social interaction are exogenous to mental and physical health.

The baseline values for physical health and mental health are the earliest recorded information for each respondent. Thus, we analyse the direct and indirect pathways from past mental and physical health to present physical and mental health through intermediate levels of physical activity, social interaction and cigarette consumption. This approach has been used in past longitudinal mediation analysis (Dour et al., 2014; Burns et al., 2015). It differs from dynamic models with lagged health because the effect of health lags is captured by the mediators. Using a baseline value that pre-dates the mediators mitigates concerns over reverse-causality and captures earlier life investments in health and health endowments. The baseline can be treated as exogenous as it reflects a constant stock of mental and physical health which is not determined by the time varying parameters in the model. The strong cross-effect state-dependence in mental and physical health further justifies the use of the initial conditions as strong predictors of present physical and mental health (Ohrnberger et al., 2017).

To estimate the indirect effects, we modify (1) and (2) into (3) and (4) respectively by adapting the notation of Han et al. (2011)

$$P_{it} = \beta_0 + \beta_1 P_{it=0} + \beta_2 M_{it=0} + \beta_3 PhysAct_{it-1}(M_{it=0}) + \beta_5 CIG_{it-1}(M_{it=0}) + \beta_6 SCIndex_{it-1}(M_{it=0},) + \mathbf{X_{it}}\beta_7 + v_{it} \quad (3)$$

$$M_{it} = \beta_0 + \beta_1 P_{it=0} + \beta_2 M_{it=0} + \beta_3 PhysAct_{it-1}(P_{it=0}) + \beta_5 CIG_{it-1}(P_{it=0}) + \beta_6 SCIndex_{it-1}(P_{it=0},) + \mathbf{X_{it}}\beta_7 + \rho_{it} \quad (4)$$

We assume that the indirect effects of past mental health on current physical health and of past physical health on current mental health are mediated through lagged effects of the individual health investments, including past physical activity ($PhysAct_{it-1}$), past social interactions ($SCIndex_{it-1}$), and past cigarette consumption (CIG_{it-1}). We disentangle the direct from the indirect effects by total differentiation of physical health with respect to our mental health component $M_{it=0}$, and our physical health component $P_{it=0}$ respectively:

$$\frac{dP}{dM} = \beta_2 + \left(\frac{\partial P}{\partial PhysAct} \times \frac{\partial PhysAct}{\partial M}\right) + \left(\frac{\partial P}{\partial CIG} \times \frac{\partial CIG}{\partial M}\right) + \left(\frac{\partial P}{\partial SC.Index} \times \frac{\partial SC.Index}{\partial M}\right) \quad (5)$$

$$\frac{dM}{dP} = \beta_2 + \left(\frac{\partial M}{\partial PhysAct} \times \frac{\partial PhysAct}{\partial P}\right) + \left(\frac{\partial M}{\partial CIG} \times \frac{\partial CIG}{\partial P}\right) + \left(\frac{\partial M}{\partial SC.Index} \times \frac{\partial SC.Index}{\partial P}\right) \quad (6)$$

The right hand-side of (5) decomposes the total effect of past mental health on present physical health into: (i) the direct effect of the stock of past mental health, β_2; and (ii) the indirect effect (terms in parentheses) as cross-derivatives. The first term in parentheses denotes the indirect effect through physical activity. The second term reflects the indirect effect through cigarette consumption. The third term gives the indirect effect through social interactions. Equation (6) is the equivalent of (5) for the effects of past physical health on present mental health.

The mediating factors in (5) and (6) are estimated in three additional equations (7)–(9). Equation (7) captures the effect of both past mental health and past physical health on past physical activity

$$PhysAct_{it-1} = \gamma_0 + \gamma_1 M_{it=0} + \gamma_2 P_{it=0} + \mathbf{X_{it-1}}\gamma_3 + \tau_{it-1} \quad (7)$$

with additional covariates $\mathbf{X_{it-1}}$, and the error component τ_{it-1}.

Equation (8) shows the effect of past mental and physical health on cigarette consumption

$$CIG_{it-1} = \alpha_0 + \alpha_1 M_{it=0} + \alpha_2 P_{it=0} + \mathbf{X_{it-1}}\alpha_3 + \omega_{it-1} \quad (8)$$

where ω_{it-1} is the error term. To quantify the effect of the stock of past mental and physical health on social interaction, equation (9) is estimated with the error term ϕ_{it-1}.

$$SCIndex_{it-1} = \eta_0 + \eta_1 M_{it=0} + \eta_2 P_{it=0} + \mathbf{X_{it-1}}\eta_3 + \phi_{it-1} \quad (9)$$

The computation of the indirect effects is similar to the product method discussed by Baron and Kenny (1986). For example, in order to calculate the indirect effect of mental health on physical health through social interaction, the coefficient η_1 is multiplied by the β coefficient for social interaction, which reflects the association of social interaction with physical health in equation (1).

We assume that the errors v_{it} and ρ_{it} in equations (1) and (2) are uncorrelated. Potential interrelations of mental and physical health are accounted for by the inclusion of baseline health values. We account for

unobserved heterogeneity by including random effects (RE) in all equations, assuming a composite error term $v_{it} = \mu_i + \varepsilon_{it}$ with time-invariant individual component μ_i and time-varying error ε_{it}. OLS introduces bias into the coefficient estimates by not accounting for heterogeneous effects as has been shown in Ohrnberger et al. (2017). Fixed Effects or Correlated Random Effects are not applicable as they lead to downwardly biased estimates of the lagged variables because of the low number of time points (Contoyannis and Li, 2011). RE rules out correlation between the regressors and the unmeasured variability across individuals. This is an important assumption for our model where choices of health investments and consumption are maximised over health requiring that errors are not serially correlated and choices are independent of previous choices. Another advantage of using RE for our model estimation is that the effects of important explanatory individual time-invariant predictors such as health baseline values, educational attainment, gender or ethnicity are estimated.

We approach the estimation as follows: Firstly, we estimate the entire model (equations (1) and (2)) with the full sample and for subgroups of gender and age (50–60; 60–70; 70–80; 80 + years). Secondly, we estimate each of the three additional equations (7)–(9) of the potential mediators for the full sample and the sub-groups. Finally, we estimate the direct effects, indirect effects, and total effects and bootstrap their values. Bootstrapping takes both the longitudinal structure and the random effect error assumption into account.

4.1. Robustness analysis

We undertake three forms of robustness analysis. First, we add $CIG_{it=0}$ and CIG_{it-2} to equations (1), (2) and (8) which is the classical dynamic model structure with $CIG_{it=0}$ being the initial smoking condition reflecting attitudes to smoking and the stock of addiction and CIG_{it-2} being the second lag estimator of smoking (Contoyannis et al., 2004). Second, in equations (5) and (6) we include the second-period lagged values of our lifestyle and social capital variables. Third, we test for attrition in running the analysis on a balanced panel and by including a dummy variable that switches from zero to one if the individual leaves the survey in the following round.

Ethics approval is not required for this study. All data used in this study is available publicly from the NHS Health and Social Care Information Centre. As a result, no data was collected directly from human subjects.

5. Results

5.1. Models for the direct effects

The estimated coefficients for the full sample are reported in Table 2. Subsample analyses by age and gender are presented in appendix tables A1 for physical health and A2 for mental health. For the physical health models, the coefficient of baseline physical health is positive and statistically significant in all specifications. This effect is stronger for the sample of 50–60 year-olds. The baseline value of mental health has a statistically significant and positive direct effect on present physical health. The magnitude of past mental health increases gradually across age quartiles, indicating stronger mental health effects in older age groups. No differences are observed in the effects of baseline mental health between males and females.

Past physical activity and social interactions improve physical health. Physical health is further explained by a set of covariates varying across the subgroups. Age has a non-linear relationship with health, with a positive effect up to 57 years and then a negative effect thereafter. Higher education has a positive effect on physical health in all but the second and the fourth age-quartiles (table A1 in the appendix). Associations of mental health with baseline physical and mental health, physical activity and social interaction are similar to those in the physical health models (Table 2 (2) and table A2 in the appendix).

5.2. Models for the mediators

Columns (3) to (5) in Table 2 display the estimates from the physical activity, smoking, and social interaction models for the full sample. Subsample analyses by age and gender are presented in the appendix tables A3 to A5. We find that better baseline mental health increases the intensity of physical activity on average by about 10% in the full sample in Table 2 (3). The baseline value of mental health is significant and positively associated with physical activity with similar magnitudes in the different samples (table A3). A one unit increase in baseline mental health implies a 4% increase in the intensity of physical activity on average.

Column 4 in Table 2 shows the estimates of the past cigarette smoking model for the full sample. Past cigarette smoking is strongly associated with baseline mental health. Better baseline mental health decreases the average number of smoked cigarettes by about 16%. Subsample analysis presented in table A4 shows that the effect decreases over age from the first age-quartile with −0.363 to the fourth age-quartile −0.096. The coefficient is slightly stronger for females with −0.237 than it is for males with −0.205.

Past social interactions are also positively associated with baseline mental health. Subsample analysis presented in table A5 shows that this association decreases in age and is stronger for males (0.099) compared to females (0.078).

5.3. Estimates of the mediating effects

Table 3 presents the bootstrapped estimates of the mediation analysis of the full sample on physical health in column (1) and mental health in column (2). Analyses by sub-samples are presented in the appendix tables A6 and A7.

The mediation analysis on physical health shows that the effect of baseline mental health on present physical health is significantly mediated by past physical activity and by past social interaction. Better past mental health at baseline has positive effects on both social interaction and physical activity which in return exert positive effects on present physical health. The total indirect effect, the direct effect, and the total effect of past mental health on physical health are statistically significant. The total indirect effect accounts for 9.7% of the full effect of mental health on current physical health. Physical activity explains the main share (77.27%) of the total indirect effect. Social interaction explains 13.63% of the total indirect effect. The share of the indirect effect in the total effect through physical activity is 7.55%. Social interaction explains 1.33% of the total effect of past mental health on present physical health.

The mediation analysis on mental health in column (2) shows that the total indirect effect, direct effect, total effect and the share of the total indirect effect in the total effect, are all significant and positive. Only physical activity mediates the effect of baseline physical health on current mental health, with a positive association. Better baseline physical health is positively correlated with physical activity which has a positive impact on current mental health. The total effect is positive and increases present mental health by about 3.5%. Physical activity explains all of the total indirect effect of past physical health with present mental health. The proportion of the total indirect effect of baseline physical health with present mental health is 8%.

Table A6 presents the results of the mediation analysis of past mental health with present physical health by age groups and gender. We find significant mediation effects through past physical activity in all sub-samples, past cigarette consumption for 50–60 year old, and past social interaction for 70–80 year old and females. The association of the mediators is positive with present physical health. The total indirect effect, direct effect, and total effect are statistically significant across all sub-samples. The total indirect effect and total effect increase with age.

Table 2
Random effects regression models for physical health, mental health, physical activity, smoking, and social interactions.

	(1)	(2)	(3)	(4)	(5)
	ADL	CES	PA (t-1)	CIG (t-1)	SI (t-1)
Physical Activity (t-1)	0.067***	0.087***			
	(0.006)	(0.013)			
Cigarettes (t-1)	−0.001	−0.013***			
	(0.001)	(0.003)			
Social Interaction (t-1)	0.007***	0.013**			
	(0.002)	(0.005)			
ADL baseline	0.601***	0.240***	0.245***	0.023	−0.008
	(0.016)	(0.021)	(0.009)	(0.062)	(0.025)
CES baseline	0.041***	0.432***	0.051***	−0.225***	0.086***
	(0.004)	(0.010)	(0.004)	(0.031)	(0.011)
Male	−0.009	0.228***	0.070***	−0.042	−0.415***
	(0.012)	(0.025)	(0.012)	(0.092)	(0.038)
White	−0.003	0.257**	0.161***	1.267***	0.239*
	(0.050)	(0.104)	(0.045)	(0.204)	(0.129)
Age	0.045***	0.083***	0.066***	−0.277***	0.086***
	(0.009)	(0.017)	(0.008)	(0.039)	(0.020)
Age Squared	−0.000***	−0.001***	−0.001***	0.002***	−0.001***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Higher Education	0.039***	0.114***	0.163***	−0.844***	−0.277***
	(0.013)	(0.027)	(0.013)	(0.101)	(0.040)
Household Size	−0.011	0.113***	−0.016**	−0.127***	0.172***
	(0.008)	(0.017)	(0.007)	(0.043)	(0.020)
Private Insurance	0.006	0.044	0.064***	−0.182***	−0.008
	(0.012)	(0.028)	(0.013)	(0.065)	(0.032)
Retired	0.012	0.097***	0.039***	−0.145***	0.118***
	(0.011)	(0.026)	(0.012)	(0.054)	(0.027)
Log-equivalised household income	0.006	0.106***	0.036***	−0.081**	−0.022
	(0.007)	(0.017)	(0.008)	(0.036)	(0.016)
Constant	0.425	−2.101***	−2.003***	15.088***	3.356***
	(0.347)	(0.632)	(0.279)	(1.482)	(0.709)

All models are estimated on the full sample size with 10,693 individuals and 29,944 observations. For models (3)–(5) the time-variant covariates take on (t-1)-lagged values (e.g. Age (t-1), Age Squared (t-1), Higher Education (t-1), Household Size (t-1), Private Insurance (t-1), Retired (t-1), Log-equivalised household income (t-1)). We control in all models for year and regional effects. Robust standard errors in parentheses; ***p < 0.01, **p < 0.05, *p < 0.1.

Table 3
Mediation effects on physical health and mental health.

	(1)	(2)
	Physical Health Mediation	Mental Health Mediation
(A) indirect physical activity	0.0034***	0.0213***
	(0.0004)	(0.0032)
(B) indirect cigarette	0.0003	−0.0003
	(0.0003)	(0.0008)
(C) indirect social interaction	0.0006***	0.0001
	(0.0002)	(0.0003)
(A + B + C) total indirect effect	0.0044***	0.021***
	(0.0006)	(0.0035)
(D) direct effect	0.041***	0.24***
	(0.004)	(0.021)
(A + B + D + C) total effect	0.045***	0.261***
	(0.0041)	(0.021)
Total indirect/total effect	0.097***	0.08***
	(0.015)	(0.0149)

The pathway in model (1) is baseline CES with the outcome ADL. The pathway in model (2) is baseline ADL with the outcome CES. Both models are estimated on the full sample size with 10,693 individuals and 29,944 observations. Bootstrapped standard errors in parentheses ***p < 0.01, **p < 0.05, *p < 0.1; Based on 200 replications; we tested for more replications without significant differences.

The share of the total indirect effect in the total effect is lowest for 60–70 year olds (7.9%) and highest for 50–60 year olds (12.9%). Physical activity explains the main share of the total indirect effect. It varies across the subsamples between 47.22% (Age 50–60) and 93.81% (Age 80+) and is stronger for males than for females. The share of physical activity in the total effect ranges from 6.2% for Age (50–60) to 10.8% for Age (80+). Social interaction explains 1.3% of the total indirect effect and 0.19% of the total effect amongst 70–80 year olds. For females, social interaction explains 18.2% of the total indirect effect and 1.74% of the total effect. Cigarette smoking explains 41.7% of the total indirect effect and 5.4% of the total effect for 50–60 year olds.

The sub-sample analysis by age groups and gender on mental health, presented in table A7, is consistent with the full sample analysis in finding that only physical activity mediates the effect of baseline physical health with current mental health. The total indirect effect is positive, increases by age and is stronger for females. The total effect is positive and moderated by age groups with decreasing magnitudes from the first (0.307) to the fourth (0.158) age-group. It is more pronounced for females (0.627) than males (0.045). The proportion of the total indirect effect of past physical health on present mental health explained by the mediators ranges from 2.5% (Female) to 13.6% (Age 70–80), and is higher for males (9.9%) than females (2.5%).

5.4. Robustness test of stock of addiction and time-lags in mediators

The findings on robustness are presented in the tables as follows: for the stock of addiction in cigarette consumption (A8) and (A9); two-period lagged mediators (A10) and (A11); mediation analysis for the two-period lagged mediators and the stock of addiction in cigarette consumption is in table A12 in the appendix.

We find similar results for the indirect and direct effects for both mental health and physical health mediation models with and without the stock of addiction. Our main findings are robust to including t-2 lagged mediators in equations (5) and (6). We do not find any qualitative changes when the coefficients are estimated on a balanced sample or when an indicator for attrition is included.

6. Discussion & conclusion

We examined the direct and indirect effects of mental health on physical health and vice versa, through a mediation analysis. We developed a mediation framework and tested whether the effects of mental health on physical health and physical health on mental health are mediated by lifestyle choices (physical activity, number of cigarettes smoked) and social capital (social interaction). This is a novel contribution and important in understanding the pathways of mental and physical health for both research and policy. We use six waves of the ELSA (2002–2012), and investigate potential mediating effects on the full sample size and heterogeneous effects by age-quartiles and gender.

We find that past mental (physical) health has a significant direct and indirect impact on physical (mental) health. The indirect effect of past mental health on physical health is mediated by lifestyle choices and social interactions. The relationship of past physical health with present mental health is only mediated by past physical activity.

Physical activity explains 8% of the total effect of past physical health on mental health and 7.5% of the total effect of past mental health on physical health. The indirect effect of physical activity on both physical and mental health is positive, generated by the positive association of better physical and mental health with physical activity. Better physical and mental health status therefore leads to more physical activity which in return has a positive association with better mental health and physical health. Gerber and Puehse (2009) have found a similar positive association between mental health and physical activity.

Past social interaction has a positive direct effect on mental and physical health. It explains approximately 13.6% of the total indirect effect in physical health. The positive association of social ties with mental health has previously been found (Umberson and Montez 2010). Previous research also supports the positive relationship with physical health. An explanation for this effect is that social interactions favour good health behaviours and vice versa (Umberson et al., 2010).

Better past mental health is found to reduce cigarette consumption, which then has a positive effect on present physical health. Szatkowski and McNeill (2015) find more than doubled smoking rates among the English population with mental health disorders compared to the English population without mental health disorders.

A limitation of this paper is that only a set of three mediators is considered whereas other factors such as socio-economic status, dietary choices or medical care may be important. Whilst we justify the choice of mediators with a conceptual framework, existing literature, key policy relevance and data availability, we note that we can only capture a lower bound estimate for the mediator effects and an upper bound for the direct effects. Further studies are needed to consider a broader set of mediators. Future studies should also aim to examine specific health interventions for the older population and the long-term cross-effects on both mental and physical health.

The main finding of this paper is that past mental and physical have strong indirect cross-effects on current mental and physical health. The key indirect pathways are past cigarette consumption, past physical activity and past social interaction. Similar associations apply for the relationship between past mental health and present physical health.

Our results imply that health investments and social interactions may be considered intervention channels through which mental and physical health can be improved at old age. In addition we have found heterogeneous indirect cross-effects in health. Physical health activity is important throughout the life-cycle from 50+, but is stronger for higher age groups.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.socscimed.2017.11.008.

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