Influence of individual and combined healthy behaviours on successful aging

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Abstract

Background: Increases in life expectancy make it important to remain healthy for as long as possible. Our objective was to examine the extent to which healthy behaviours in midlife, separately and in combination, predict successful aging.

Methods: We used a prospective cohort design involving 5100 men and women aged 42–63 years. Participants were free of cancer, coronary artery disease and stroke when their health behaviours were assessed in 1991–1994 as part of the Whitehall II study. We defined healthy behaviours as never smoking, moderate alcohol consumption, physical activity (≥ 2.5 h/wk moderate physical activity or ≥ 1 h/wk vigorous physical activity), and eating fruits and vegetables daily. We defined successful aging, measured over a median 16.3-year follow-up, as good cognitive, physical, respiratory and cardiovascular functioning, in addition to the absence of disability, mental health problems and chronic disease (coronary artery disease, stroke, cancer and diabetes).

Results: At the end of follow-up, 549 participants had died and 953 qualified as aging successfully. Compared with participants who engaged in no healthy behaviours, participants engaging in all 4 healthy behaviours had 3.3 times greater odds of successful aging (95% confidence interval [CI] 2.1–5.1). The association with successful aging was linear, with the odds ratio (OR) per increment of healthy behaviour being 1.3 (95% CI 1.2–1.4; population-attributable risk for 1–4 v. 0 healthy behaviours 47%). When missing data were considered in the analysis, the results were similar to those of our main analysis.

Interpretation: Although individual healthy behaviours are moderately associated with successful aging, their combined impact is substantial. We did not investigate the mechanisms underlying these associations, but we saw clear evidence of the importance of healthy behaviours for successful aging.

Increases in life expectancy make remaining free of disease and in good functional health for as long as possible an important objective for the present and future generations.[1] Most research in this domain has focused on risk factors for single health outcomes, such as mortality, chronic diseases or functioning. However, good health at older ages is a multidimensional concept, having been defined variously with reference to absence of disease and good functional status.[2–5] There is considerable research on disability outcomes at older ages,[2,6–8] but less attention has been paid to successful aging combining favourable functioning outcomes with good mental health and the absence of chronic diseases and disability.[9–13]

Smoking, alcohol consumption, poor diet and physical inactivity are among the top 10 leading risk factors for death and disability in intermediate- and high-income countries.[14] There is increasing interest in the combined effect of these behaviours on health. Studies show that people who engage in multiple unhealthy behaviours have a higher risk of death,[15–23] chronic disease[24–30] and poor cognitive function than people who do not engage in as many unhealthy behaviours.[31] However, whether healthy behaviours determine good functional status at older ages, combined with the absence of chronic diseases, remains unknown.

Our objective was to examine the extent to which individual and combined healthy behaviours in midlife predict successful aging about 16 years later, at 60 years of age or older. We used a comprehensive definition of successful aging that included having good mental health, having good cognitive, physical and cardiorespiratory function, and being free of disability and chronic disease (coronary artery disease, stroke, diabetes and cancer).

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Materials and methods

Study population

We used data from the Whitehall II cohort study, which was established in 1985–1988 and involving 10 308 British civil servants (67% men) aged 35–55 years.[32] Participants gave their written consent to participate in the study, and the ethics committee of the University College London approved the study. The Whitehall II study design consists of a clinical examination about every 5 years: 1985–1988, 1991–1994, 1997–1999, 2002–2004 and 2007–2009.

The target population of our study comprised all participants of this occupational cohort for whom data on healthy behaviours in 1991–1994 were available, and who were at least 60 years old at the end of follow-up (2008–2009), with no history of stroke, myocardial infarction or cancer in 1991–1994 (n = 6599). Our analysis included the 5100 participants for whom data on the outcome variables were available (Figure 1).

Baseline measures (1991–1994)

We assessed participants' healthy behaviours based on their responses to a questionnaire. We categorized smoking status as "current," "former" and "never smoked." We assessed alcohol consumption by asking for the number of alcoholic drinks consumed in the past 7 days, and categorized consumption as "abstinence from alcohol" (no alcohol in the last week), "moderate alcohol consumption" (1–14 units/wk for women; 1–21 units/wk for men)[33] and "heavy alcohol consumption" (≥ 15 units/wk for women; ≥ 21 units/wk for men). A participant's level of physical activity was categorized as "active" (≥ 2.5 h/wk moderate physical activity or ≥ 1 h/wk vigorous physical activity) or "inactive" (no physical activity).[31,34] We assessed dietary behaviour by asking for the frequency with which fruits and vegetables were eaten.

We defined participants as having healthy behaviours if they met the following criteria: never smoked, moderate alcohol consumption,[17,33] physically active, and eating fruits and vegetables daily. For further information on this categorization, see Appendices 1 and 2 (available at www.cmaj.ca/lookup/suppl/doi:10.1503/cmaj.121080/-/DC1).

The sociodemographic variables in our analysis were age, sex, marital status and level of education (5-level variable), as described previously.[35]

Outcome assessment (from 1991–1994 to 2008–2009)

We assessed mortality using the national mortality register kept by the National Health Services Central Registry and the National Health Service identification numbers assigned to each British citizen. Among surviving participants, we defined successful aging at 60 years of age or older as satisfying each of following criteria: no history of cancer, coronary artery disease, stroke or diabetes; good cognitive, physical, respiratory and cardiovascular functioning, and the absence of disability; and good mental health.

We assessed chronic diseases throughout follow-up (from 1991–1994 to 2007–2009). We determined the incidence of coronary artery disease using clinically verified events, including myocardial infarction and definite angina. We defined nonfatal myocardial infarction using the Monitoring Trends and Determinants of Cardiovascular Disease (MONICA) criteria,[36] and determined its incidence using data from resting electrocardiographs (ECGs) taken during the Whitehall II study, hospital records of ECGs and cardiac enzyme levels. We identified definite angina using a questionnaire[37] and corroborated cases with medical records or abnormal results on resting ECG, exercise ECG or coronary angiography.[38] We assessed stroke using a self-reported measure of physician diagnosis. We defined diabetes mellitus as a fasting blood glu-

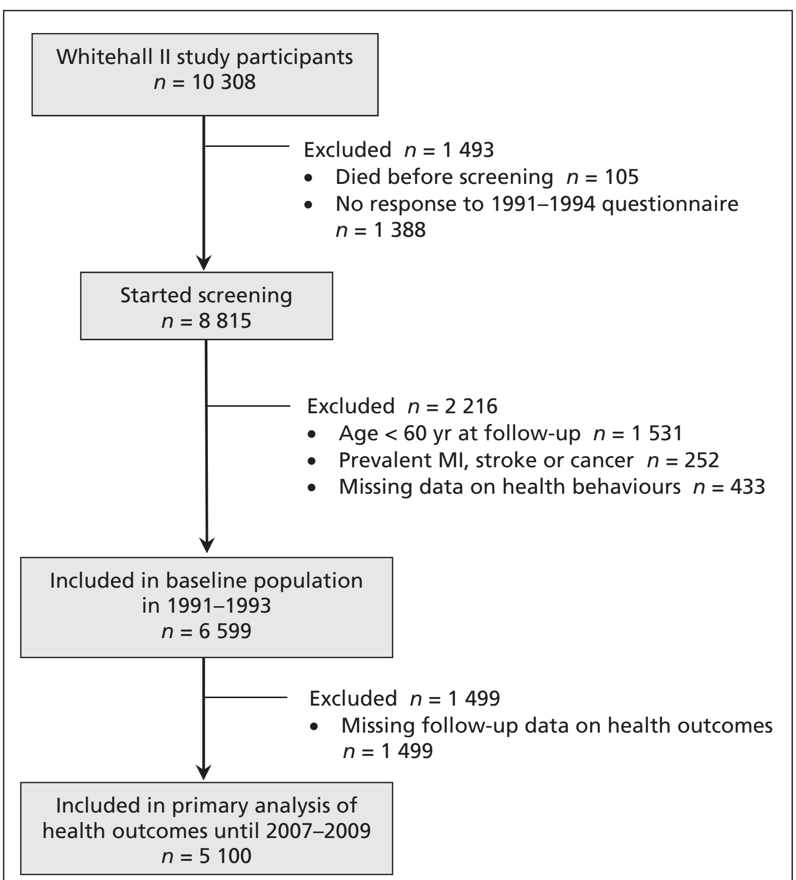

Figure 1: Selection of participants for the study. MI = myocardial infarction.

cose level of 7.0 mmol/L or more, a 2-hour post-load blood glucose level of 11.1 mmol/L or more, self-reported doctor-diagnosed diabetes or the use of medications for diabetes.[39] We identified cases of cancer using the National Health Service's cancer register.

We assessed disability based on participants' responses to 14 questions on perceived difficulties in basic[40] and instrumental activities of daily living.[41] Participants with difficulties in one or more activities were considered to have a disability.

We assessed functioning during the 2007–2009 clinical examinations using standard protocols (Appendix 1). We defined poor functioning as scores in the lowest sex- and age-standardized quintile (i.e., below the 20th percentile) for each measure of functioning, with the exception of blood pressure. For blood pressure, the highest quintile (i.e., above the 80th percentile) was used. We assessed cognitive functioning using a score of global cognition calculated from 5 cognitive tests;[42] we assessed physical functioning using walking speed measured over an 8-foot-long course;[43,44] we assessed respiratory function using forced expiratory volume in 1 second;[44] and we assessed cardiovascular function using systolic blood pressure (an average of 2 measurements in a sitting position after a 5-min rest using a sphygmomanometer [OMRON HEM 907]).

We defined good mental health as a score of more than 42 points on the mental health component of the short-form general health survey[45,46] included in the 2007–2009 questionnaire.

Statistical analysis

We defined 3 categories of outcome: successful aging, death during follow-up and normal aging. The normally aging group included all participants who were alive at the end of follow-up, but who were not classified as aging successfully. We performed 2 separate logistic regressions: the first to estimate the odds ratios (ORs) for successful aging (with normal aging/death as the noncases), and the second to estimate the ORs for survival (with death as the noncases). To test whether the associations with healthy behaviours differed by sex, we tested statistical interactions between each behaviour and sex using the Wald test.

To estimate the contribution of healthy behaviours to successful aging, we calculated population-attributable risk (PAR) for individual and combined healthy behaviours. Population-attributable risk is the reduction in the rate of a disease that would be seen if the population were entirely unexposed to the risk factor, compared with the current pattern of exposure. Applied to successful aging, PAR represents the gain in cases of successful aging that would be achieved if everyone engaged in healthy behaviours, assuming that the association between healthy behaviours and successful aging is causal. The relation can be expressed by the following equation:

$$\text{PAR} = f(\text{OR} - 1)/(1 + f(\text{OR} - 1)$$

where f is the proportion of healthy behaviours in the total population at baseline, and OR is the odds ratio for successful aging for the specific healthy behaviour compared with the reference. We adjusted these estimates for covariates in a fashion similar to the corresponding logistic models for ORs.

In our first set of analyses, healthy behaviours were entered together in a model adjusted for age, sex, level of education and marital status. We then used the same method to assess the association between the number of healthy behaviours and successful aging and survival. To test whether there was a dose–response relation between the number of healthy behaviours and each outcome, we treated the number of healthy behaviours in the logistic model as a continuous variable; the Wald test p for this variable was the test for linear trend, and p less than 0.05 was considered significant. Finally, we examined separately the association between the number of healthy behaviours and each measure of func-

Table 1: Baseline characteristics of participants included in the analysis in comparison with those excluded because of missing data on health outcomes

	No. (%)*		
Characteristic	Study participants n =5100	Excluded participants n =1499	p value
Age, yr, mean ± SD	51.3 ± 5.3	51.4 ± 5.1	0.5†
Female sex	1506 (29.5)	579 (38.6)	< 0.001‡
Married or living with someone	3963 (77.7)	1118 (74.6)	0.01‡
University degree or higher	1274 (25.0)	303 (20.2)	0.001‡
Never smoked	2500 (49.0)	722 (48.2)	0.6‡
Moderate consumption of alcohol	3271 (64.1)	912 (60.8)	0.02‡
Physically active	2602 (51.0)	721 (48.1)	0.05‡
Daily consumption of fruits and vegetables	3200 (62.7)	884 (59.0)	0.01‡

Note: SD = standard deviation.
*Unless otherwise indicated.
†t test.
‡χ^2 test.

Table 2: Comparison of characteristics between participants in the successful and normal aging groups

Characteristic	Successful aging* n = 953	Normal aging† n = 3598
At baseline		
Age, yr, mean ± SD	49.7 ± 4.9	51.3 ± 5.3
Married or living with someone, no. (%)	774 (81.2)	2798 (77.8)
University degree or higher, no. (%)	301 (31.6)	872 (24.2)
Female sex, no. (%)	247 (25.9)	1087 (30.2)
At follow-up		
Coronary artery disease, no. (%)	0 (0)	581 (16.1)
Stroke‡, no. (%)	0 (0)	178 (5.3)
Cancer‡, no. (%)	0 (0)	614 (17.1)
Diabetes mellitus‡, no. (%)	0 (0)	618 (17.1)
≥ 1 limitation in ADL/IADL, no. (%)	0 (0)	581 (16.2)
Systolic blood pressure, mm Hg, mean ± SD	120.2 ± 10.9	128.9 ± 17.6
Forced expiratory volume, L/m^2, mean ± SD	1.1 ± 0.2	0.9 ± 0.2
Walking speed, m/s, mean ± SD	1.3 ± 0.2	1.1 ± 0.3
Cognitive function, z score, mean ± SD	0.5 ± 0.7	–0.2 ± 1.0
Mental health score, mean ± SD	56.3 ± 4.2	52.9 ± 9.2

Note: ADL = activities of daily living, IADL = instrumental activities of daily living, SD = standard deviation.
*For criteria defining successful aging, see Methods.
†Participants who were alive at the end of follow-up, but who were not classified as successful agers.
‡Calculated using available data. For stroke, data were missing for 239 participants; for cancer, data were missing for 6 participants; for diabetes, data were missing for 5 participants.

tioning using separate logistic regression models for each functioning outcome. The p for trend was estimated using the p associated with the number of healthy behaviours when entered as a continuous variable in the logistic regression models.

We did several sets of sensitivity analyses. To assess whether the association with successful aging was influenced by deaths, we excluded deaths from the analytic sample. In addition, because scores on the mental health component of the 2007–2009 questionnaire are known to improve with age, we tested the robustness of our results using age- and sex-specific quintiles to define good mental health. Finally, to examine the extent to which missing data influenced our results, we used inverse probability weighting (see Appendix 1 for further details).[47]

Results

We included 5100 participants in the study. The mean age of participants was similar to that of the 1499 people excluded from our analysis because of missing data on health outcomes (51.3 v. 51.4 yr, p = 0.50) (Table 1). However, the analytic sample comprised fewer women (29.5% v. 38.6%, p < 0.001) and more participants with healthy behaviours other than smoking (Table 1).

Among participants, 549 died during follow-up, and 953 met the criteria for successful aging

Table 3: Association between healthy behaviours, successful aging and survival to end of follow-up among 5100 participants

Healthy behaviour	Total population	Successful aging* n = 953: No. of people	Successful aging*: Adjusted OR‡ (95% CI)	Successful aging*: PAR, %	Survival*† n = 4551: No. of people	Survival*†: Adjusted OR‡ (95% CI)	Survival*†: PAR, %
Never smoked							
No (reference)	2600	422	1.00		2259	1.00	
Yes	2500	531	1.29 (1.11–1.49)	12.4	2292	1.53 (1.27–1.85)	20.6
Moderate consumption of alcohol							
No (reference)	1829	287	1.00		1589	1.00	
Yes	3271	666	1.31 (1.12–1.53)	16.6	2962	1.40 (1.16–1.68)	20.4
Physically active							
No (reference)	2498	386	1.00		2187	1.00	
Yes	2602	567	1.45 (1.25–1.68)	18.7	2364	1.32 (1.10–1.60)	14.0
Daily consumption of fruits and vegetables							
No (reference)	1900	292	1.00		1658	1.00	
Yes	3200	661	1.35 (1.15–1.58)	18.1	2893	1.33 (1.10–1.60)	17.2

Note: CI = confidence interval, OR = odds ratio, PAR = population-attributable risk.
*The binary outcomes are successful aging versus normal aging or death, and survival to the end of follow-up versus death.
†Includes successful and normal aging groups.
‡Adjusted for age, sex, level of education and marital status, mutually adjusted for each healthy behaviour.

at the end of follow-up. Compared with the normally aging group, participants in the successfully aging group were younger (mean age 49.7 [standard deviation (SD) 4.9] v. 51.3 [SD 5.3] yr), and were more likely to be married (81.2% v. 77.8%) and have a university education or higher (31.6% v. 24.2%) (*t* test for continuous variables, χ^2 test for categorical variables, all $p < 0.001$) (Table 2).

Table 3 shows the association of each healthy behaviour with successful aging and staying alive for the duration of follow-up (i.e., survival). Because there was no interaction between healthy behaviours and sex (data not shown, Wald test, all $p > 0.17$), we combined men and women in the analysis. Compared with former and current smokers, participants who had never smoked had 1.3 times greater odds of meeting the criteria for successful aging (OR 1.29, 95% confidence interval [CI] 1.11–1.49; PAR 12.4%) and 1.5 times greater odds of survival (OR 1.53, 95% CI 1.27–1.85; PAR 20.6%) (Table 3). Compared with no and heavy alcohol consumption, moderate consumption was associated with greater odds of successful aging (OR 1.31, 95% CI 1.12–1.53; PAR = 16.6%) and survival (OR 1.40, 95% CI 1.16–1.68; PAR 20.4%) (Table 3). Compared with inactive participants, participants who were physically active were more likely to meet the criteria for successful aging (OR 1.45, 95% CI 1.25–1.68; PAR = 18.7%) and to be alive at the end of follow-up (OR 1.32, 95% CI 1.10–1.60; PAR 14.0%) (Table 3). Finally, consuming fruits and vegetables daily was associated with greater odds of successful aging (OR 1.35, 95% CI 1.15–1.58; PAR 18.1%) and survival (OR 1.33, 95% CI 1.10–1.60; PAR 17.2%) (Table 3).

In our study population, 4.9% of the participants engaged in no healthy behaviours (score = 0), 18.3% engaged in 1 (score = 1), 33.8% engaged in 2 (score = 2), 31.3% engaged in 3 (score = 3), and 11.8% engaged in 4 (score = 4) (data not shown). The mean change in score 5 years later was small for both the normally aging group (0.08 ± 0.95) and the successfully aging group (0.00 ± 0.95) (data not shown). By the end of follow-up, the mean score for healthy behaviours had increased in both groups (0.10 ± 1.00 for the normally aging group; 0.17 ± 0.95 for the successfully aging group) (data not shown). The correlation between repeated measurements of the score was 0.58 (Spearman correlation, $p < 0.001$, $n = 4381$) at 5 years' follow-up and 0.53 (Spearman correlation, $p < 0.001$, $n = 4186$) at the final follow-up (data not shown).

Compared with participants who engaged in no healthy behaviours at baseline, participants who engaged in 2 or more healthy behaviours had greater odds of successful aging and survival (Figure 2). The OR for having at least 1 healthy behaviour was 1.92 for successful aging (PAR 46.6%) and 2.32 for being alive at the end of follow-up (PAR 55.6%) (Figure 2). The benefit of healthy behaviours appeared to increase linearly (Wald test, $p < 0.001$): when the score for healthy behaviours was entered in the logistic model as a continuous variable, the OR per 1 additional healthy behaviour was 1.33 (95% CI

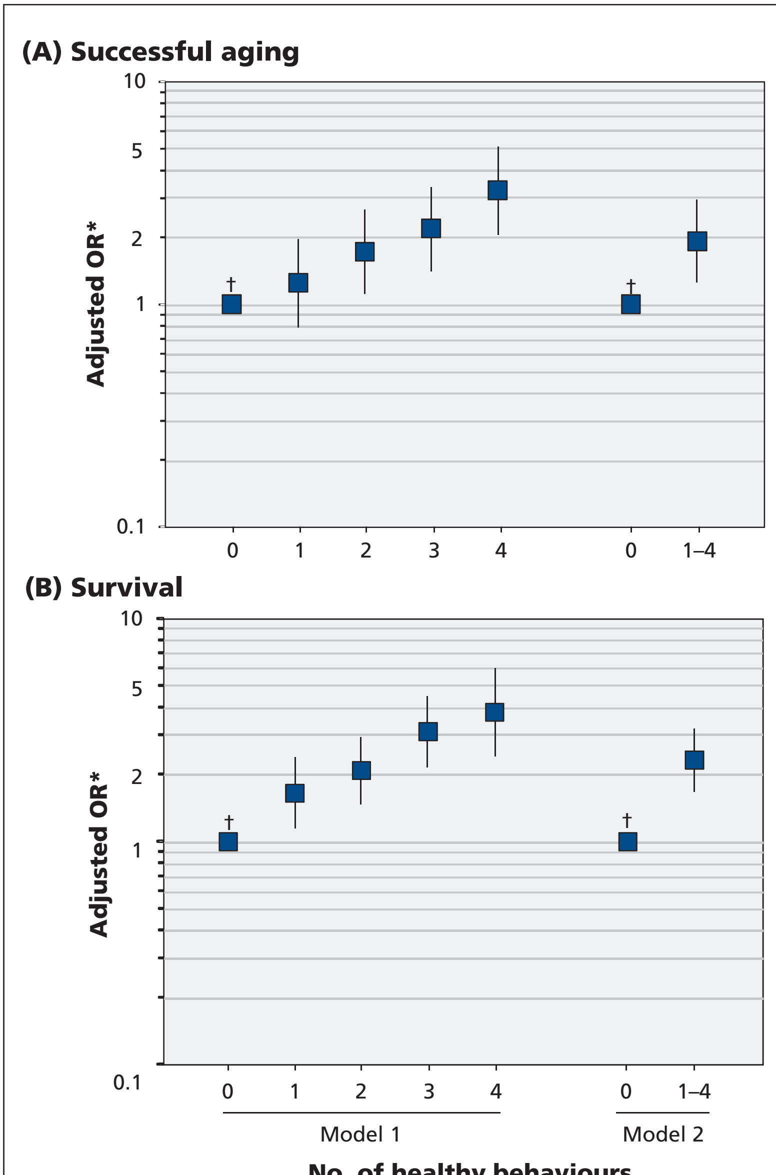

Figure 2: Association between the number of healthy behaviours participants showed at baseline and (A) successful aging or (B) survival. In model 1, each number of healthy behaviours is included in the model as a category, and ORs are calculated with "0 healthy behaviours" as the reference group. In model 2, the category 1–4 includes all participants with 1–4 healthy behaviours, and the ORs are calculated with "0 healthy behaviours" as the reference group. The binary outcomes are successful aging versus death or normal aging, and survival to the end of follow-up versus death. OR = odds ratio. Error bars indicate 95% confidence intervals. *Models were adjusted for age, sex, level of education and marital status, and were mutually adjusted for all health behaviours. †Reference.

Table 4: Associations between the number of healthy behaviours and measures of functioning used to define successful aging

No. of healthy behaviours	Measure of functioning, adjusted* OR (95% CI)						
	Good lung function†	Good cognitive function†	Good physical function†	No disability‡	Good mental health§	Good systolic BP¶	Good systolic BP or no use of antihypertensive drugs
0 (reference)	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	1.69 (1.12–2.55)	0.85 (0.58–1.26)	1.34 (0.93–1.91)	1.19 (0.81–1.74)	1.18 (0.75–1.83)	0.78 (0.50–1.22)	1.02 (0.73–1.41)
2	2.08 (1.41–3.07)	1.12 (0.77–1.63)	1.82 (1.29–2.56)	1.60 (1.11–2.31)	1.81 (1.17–2.79)	0.79 (0.55–1.15)	1.30 (0.96–1.79)
3	2.84 (1.91–4.22)	1.62 (1.10–2.37)	2.17 (1.54–3.08)	1.82 (1.25–2.63)	2.33 (1.50–3.62)	0.98 (0.71–1.39)	1.40 (1.02–1.91)
4	3.63 (2.31–5.71)	2.15 (1.39–3.33)	2.97 (1.99–4.45)	2.27 (1.49–3.47)	3.12 (1.83–5.29)	1.05 (0.80–1.71)	1.61 (1.15–2.26)
p for trend	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.4	< 0.001

Note: BP = blood pressure, CI = confidence interval, OR = odds ratio.
*Adjusted for age, sex, level of education and marital status. Numbers of participants vary from 3487 to 4455, depending on the measure of functioning (see Appendix 3 for further details).
†Defined as not being in the lowest age- and sex-standardized quintile.
‡Defined as no self-reported difficulties in basic and instrumental activities of daily living.
§Defined as score > 42 on mental component of the 2007–2009 questionnaire.
¶Defined as not being in the highest age- and sex-standardized quintile of systolic blood pressure.

1.24–1.43) for successful aging and 1.39 (95% CI 1.27–1.52) for survival.

As the number of healthy behaviours increased, so did the odds of absence of disability; good lung, cognitive and physical functioning; and mental health (Table 4, all p for trend < 0.001; Appendix 3, available at www.cmaj.ca/lookup/suppl/doi:10.1503/cmaj.121080/-/DC1). We saw no corresponding association for systolic blood pressure before taking into account antihypertensive drugs; repeating the analysis using medication data and good systolic blood pressure to define good functioning showed a clear association with the number of healthy behaviours (p for trend < 0.001).

Our sensitivity analyses showed that excluding deaths from the main analysis did not change the association between healthy behaviours and successful aging (OR per 1 additional healthy behaviour was 1.29, 95% CI 1.20–1.38; Appendix 4, available at www.cmaj.ca/lookup/suppl/doi:10.1503/cmaj.121080/-/DC1). We found similar results when alternative cut-offs for good mental health were used (OR per 1 additional healthy behaviour 1.37, 95% CI 1.27–1.47; Appendix 5, available at www.cmaj.ca/lookup/suppl/doi:10.1503/cmaj.121080/-/DC1). In addition, the results were little changed with inverse probability weighting to account for missing data (OR per 1 additional healthy behaviour 1.35, 95% CI 1.25–1.45 for successful aging; OR 1.40, 95% CI 1.29–1.53 for survival; Appendix 6, available at www.cmaj.ca/lookup/suppl/doi:10.1503/cmaj.121080/-/DC1).

Interpretation

Among members of a large cohort of British men and women 42–63 years of age at baseline, all 4 healthy behaviours examined during midlife (i.e., never smoking, moderate consumption of alcohol, engaging in some physical activity and eating fruits and vegetables daily) were associated with greater odds of successful aging during a 16-year follow-up. Compared with participants who engaged in no healthy behaviours, those who engaged in all 4 healthy behaviours had greater odds of aging successfully.

The benefits of healthy behaviours appeared to increase linearly as a function of the number of healthy behaviours present. In addition, the effect of healthy behaviours does not appear to be confined to any particular domain of successful aging. Associations were evident for each of the functional domains we measured: cognitive, mental, respiratory and cardiovascular.

Our findings advance current knowledge on successful aging.[2,7,9–13,27,48–51] Few previous studies have examined the importance of healthy behaviours for successful aging, with successful aging defined using both good functioning and the absence of disease.[10–12] The associations we saw were similar to those from previous studies,[10–12] with the exception of physical activity. The association between physical activity and successful aging has shown heterogeneity across studies. In addition, our study shows the cumulative impact of healthy behaviours on successful aging — the greater the number of healthy behaviours, the greater the benefit. Furthermore, our sensitivity analyses show that the increased risk of death associated with unhealthy behaviours does not explain our results.

Strengths and limitations

Our study's strengths include its comprehensive definition of successful aging based on a large set of objective functioning measures, its prospective design and long follow-up, and its large sample size.

We did not examine the mechanisms underlying the associations we saw in this study.

Because our results are from a study involving an occupational cohort, the participants are healthier than the general population.[52] Few of the participants engaged in very unhealthy behaviours, such as heavy alcohol consumption. For this reason, it is possible that some of the associations we report are underestimated.

We were not able to determine health status for some of the participants owing to missing data on functional outcomes. Because participants who dropped-out were more likely to have health problems,[53,54] the associations we report may be underestimated. However, sensitivity analyses using inverse probability weighting suggested that any bias due to missing data is likely to be small.

Because we assessed health behaviours using self-reports, our data could be subject to potential measurement errors.

The variables used to construct the outcomes were available at different times — chronic diseases throughout follow-up, and functioning measures at the end of the follow-up. Thus, it was not possible to examine the association between the duration of exposure and the outcomes. Such analyses may have been biased by reverse causation.

The sample population did not include anyone older than 80 years, so we were unable to examine whether our results extend to older age groups.

Conclusion

Although individual healthy behaviours are moderately associated with successful aging, their combined impact is quite substantial. Multiple healthy behaviours appear to increase the chance of reaching old age disease-free and fully functional in an additive manner. Our results should motivate lifestyle changes that not only reduce mortality and morbidity, but also improve quality of life at older ages.

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