

Title: Associations of social engagement, and loneliness with the progression and reversal of frailty: longitudinal investigations of two prospective cohorts from the UK and the USA

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Running Head: Social engagement, loneliness and frailty

Abbreviations: BRHS - The British Regional Heart Study; The Health, Aging and Body Composition Study – Health ABC; CVD - Cardiovascular disease

Associations of social engagement, and loneliness with the progression and reversal of frailty: longitudinal investigations of two prospective cohorts from the UK and the USA

Abstract

Background Social connections may impact the dynamic trajectory of frailty.

Methods Using data from the British Regional Heart Study (BRHS) in the UK (n = 715), and the US Health, Aging and Body Composition (Health ABC) Study (n = 1256), we conducted multinomial regression analyses to examine the association of baseline and change in social engagement and loneliness with progression to pre-frailty and frailty, as well as their association with reversal to pre-frailty and robust status among older adults.

Results A higher level of social engagement at baseline (BRHS: relative risk ratio (RRR) 0.69 [95%CI 0.55–0.85]; Health ABC: 0.56 [0.45–0.70]), as well as increase in social engagement (BRHS: 0.73, [0.59–0.90]; Health ABC: 0.51 [0.41–0.63]), were associated with a lower risk of developing frailty. In BRHS, a higher level of loneliness at baseline (1.42 [1.10–1.83]) and an increase in loneliness (1.50 [1.18–1.90]), increased the risk of developing frailty. For reversal of frailty, higher social engagement at baseline (Health ABC: 1.63 [1.08–2.47]) and an increase in social engagement (BRHS: 1.74 [1.18–2.50]; Health ABC: 1.79 [1.17–2.74]) were beneficial.

Conclusion Social connections maybe potentially important and modifiable factors in both preventing and reversing progression of frailty in older adults.

UNCORRECTED MANUSCRIPT

Introduction

Increased life expectancy has contributed to an ageing population, globally. Frailty, a complex age-related syndrome characterised by a cumulative deficit in many physiological systems and heightened vulnerability to stressors, is common among older adults.¹ An estimated 10% of older adults aged over 65 years are frail,² and at higher risk of falls, disability, hospitalisation, long-term care, and death.³⁻⁷ With the rapid expansion of an ageing population, the proportion of frail individuals has increased over time, which places a substantial burden on the health and social care systems.⁸ However, frailty is not inevitable. A proportion (up to three quarters) of people over 85 years old remain non-frail.¹ Moreover, as some individuals can recover from frailty,⁹ identifying factors that contribute to reversal of frailty is also important.

Measures of frailty have been developed for clinical assessment in health and social care settings. A landmark study by Fried et al. proposes a frailty phenotype model that assesses physical frailty through five criteria: unintentional weight loss, weakness or poor handgrip strength, exhaustion, slow walking speed, and low physical activity.¹⁰ Another measure frailty index proposed by Rockwood et al. is based on the cumulative deficit model that assesses frailty by a long checklist of clinical conditions and disease.¹¹ Although these two measures have been extensively validated and are widely used for assessing frailty, they are built based on different concepts and serve different purposes. The frailty phenotype is more suitable for initial stratification of the population to different frailty profiles, while frailty index summarises the results of comprehensive geriatric assessment and acts as an objective marker of deficits accumulation.¹²

Social connections, including quantitative (i.e. levels of social engagement) and qualitative (i.e. loneliness) aspects, have been theorised to contribute to a wide range of health outcomes including frailty.¹³ The concept of social engagement focuses on the structural aspects and it refers to the degree of participation in a community or society.¹⁴ Social network theory posits that participating in a wider range of social activities could promote health via reinforcing meaningful social roles and providing opportunities for individuals with companionship and sociability.¹⁵ Loneliness, on the other hand, emphasises the quality of social interactions. It is a perceived negative feeling associated with the absence of social contacts.¹⁶ Individuals can feel lonely even if they have participated in extensive social activities; conversely, individuals with low social engagement could be satisfied with the quality of their social relationships.¹⁷ Theory of loneliness posits that feeling lonely is tantamount to feeling unsafe since humans are a social species. This implicit hypervigilance for social threat in the environment can increase psychological stress, activating neurobiological (e.g. elevating sympathetic tone that is responsible for the maintenance of hypertension) and behavioural (e.g. diminishing capacity for self-regulation) mechanisms that contribute to adverse health outcomes.¹⁸ Empirical studies have shown that poor social engagement and/or feeling lonely are significantly associated with increased mortality and morbidity including cardiovascular disease, cancer, disability, depression, dementia, and cognitive decline.^{15,19-25}

Previous studies have suggested that these social connections are also linked with frailty in older adults. A study²⁶ reported that the risk of developing frailty for people with high levels of social isolation are 30% greater than those with a low level of social isolation. Similarly, people with a high level of loneliness are around 2.6 times more likely to develop frailty compared with those with lower levels of loneliness. These associations between social connections and frailty have been investigated both cross-sectionally²⁷⁻²⁹ and longitudinally.^{9,26,30,31} However, very few studies have considered the dynamic nature of individual's social engagement, loneliness and frailty status – i.e. changes in these

factors over time. Specifically, most studies have focused on healthy individuals and investigated how social engagement and loneliness were linked to the development of frailty.^{26,30-32} It remains unclear whether social engagement and loneliness could play a role in altering the frailty status of individuals who are already frail. In addition, most studies assessed social engagement and loneliness as time-invariant factors.^{9,30,31} Whether change in social engagement and loneliness influence frailty status over time is under-investigated. The current study examines the dynamic trajectories of frailty status among community-dwelling older adults. **The study is based on two population-based cohort studies of older adults in the USA and the UK, which allows assessing the validity, consistency and robustness of the associations in two population study samples in Western countries.** We also aim to examine the research questions regarding whether the baseline and changes in social engagement and loneliness affect the transition of frailty status among older adults. **In summary, the questions we examined were whether lower social engagement and higher loneliness are associated with progression to pre-frailty and frailty, and whether higher social engagement and lower loneliness are associated with reversal of frailty.**

Methods

Study Design and participants

Data from the British Regional Heart Study (BRHS) collected in the UK and the Health, Aging and Body Composition (Health ABC) Study in the USA were used in this longitudinal study. These are both complementary population-based samples of community-dwelling older adults with comparable measures and follow-up. **Examining the associations in these two studies allowed the consistency and reproducibility of the associations to be tested in two different cohort studies.**

The BRHS is an ongoing cohort study established in 1978-1980, including a socially and geographically representative population of 7735 British men aged 40-59 years from 24 towns in the UK.³³ In the analysis, baseline measures were based on data from the BRHS physical examination and questionnaires in 2010-2012; follow-up measures were from BRHS data collected in 2018. In 2010-2012, 2147 men aged 71-92 attended the study (722 attended physical examinations and 2137 completed questionnaires). Since the questionnaires in 2010-2012 did not include questions on loneliness, we used the data in 2014 as baseline. A total of 1013 men attended the follow-up study in 2018 (667 attended the follow-up examinations, and 1009 completed the questionnaires).

The Health ABC is a prospective cohort study established in the USA in 1997-1998, with the study population consisting of 3075 White and African American men and women aged 70 to 79 years. White participants were identified from a random sample of Medicare beneficiaries who lived in designated zip code areas surrounding Memphis and Pittsburgh, whereas African American participants were recruited from all age-eligible residents in these zip codes.³⁴ Physical assessment and questionnaires in 2002-2003 for participants aged 73-85 years served as a baseline for the current analysis and data collected in 2006-2007 serve as follow-up measures.

Frailty

Measure of frailty status in both the BRHS and Health ABC cohort studies was determined using the Fried frailty phenotype. Details on the measures of frailty in both studies have been fully described elsewhere,³⁵ and can be found in Supplementary Table S1. Briefly, the measure comprised five components including: unintentional weight loss, exhaustion, weakness, low physical activity and slowness. Participants with none of the components were defined as robust, 1 or 2 components as pre-frail and 3 or more as frail.

Social engagement

In both the BRHS and Health ABC studies, social engagement was measured using measures that were conceptually similar and based on whether participants engaged in the following social activities in a typical week: 1) spending time with family, friends, and neighbours; 2) doing paid work; 3) doing voluntary work; 4) playing cards, games or bingo; 5) participating in religious activities or social clubs; 6) going on holidays or overnight trips; 7) reading books or newspapers; 8) using the internet or writing letters; 9) attending courses or public meetings; 10) eating out in the restaurants or visiting the cinema, sports events, and museum etc. In the BRHS, participants were asked if they engaged in these social activities with a yes/no response. In the Health ABC, participants were asked about the frequency of these engagements in a typical week and we recoded “less than once a week” as a “no” response. Detailed information on the questions used for social engagement and corresponding coding can be found in Supplementary Table S2. Scores on social engagement ranged from 0-10, with higher scores indicating a higher level of social engagement. We calculated the change in social engagement as the score at follow-up minus the score at baseline – a positive value indicating an increase in social engagement and a negative value indicating a decrease.

Loneliness

In the BRHS, subjective perception of loneliness was measured through four questions: “how often do you feel you lack companionship?”; “how often do you feel isolated from others?”; “how often do you feel out?”; “how often do you feel in tune with the people around you?”. The response options were 1) “hardly ever or ever; 2) sometimes; 3) often. A score of loneliness was according to the sum of all items which ranged from 0 to 8.

In Health ABC, subjective feeling of loneliness was measured by one single question “I felt lonely (rarely/none, sometimes, much of the time; most/all of the time”) with a score ranging from 0 to 3. In both studies, higher scores of loneliness indicate greater loneliness. Similar to change in social engagement, change in loneliness was calculated by the score at follow-up minus the score at baseline. A positive value means an increase, while a negative value indicates a decrease in loneliness. Detailed information on measures of loneliness can be found in Supplementary Table S3.

Baseline covariates

Information related to sociodemographic measures, behavioural and health-related factors at baseline were considered to account for potential confounding effects. In the BRHS, these covariates included age, occupational social class (manual/non-manual) derived from the longest-held occupation, current smoker (yes/no), moderate to heavy alcohol consumption (yes/no), history of cardiovascular disease (CVD) or diabetes (yes/no), obesity (yes/no), and history of depression (yes/no). In Health ABC, the covariates included age, sex (male/female), **ethnicity** (white/African American), educational attainment (less than high school/high school graduate/post-secondary), history of CVD or diabetes (yes/no), obesity (yes/no), and history of depression (yes/no).

Statistical analysis

Analyses were performed separately for the BRHS and Health ABC samples. Descriptive characteristics at baseline were presented as means and standard deviations for continuous variables, or as percentages for categorical variables. Sankey diagrams were applied to present the transition of frailty

status from baseline to follow-up. We considered the probability of both processes, i.e. progressing to frailty and reversing from frailty according to social engagement and loneliness. Multinomial regression models were conducted to examine the associations of social connection (social engagement/loneliness) with progression to frailty and reversal from frailty. In the analysis of progression to frailty, samples included participants who were robust at both time points (sustained robust, which was the reference group), moved from robust to pre-frail status (progression to pre-frailty) and moved from robust/pre-frail to frail status (progression to frailty). For the reversal of frailty, analytical sample included participants who were frail at both time points (sustained frail, which was the reference group), and those who improved their frailty status from frail to pre-frail (reversal to pre-frailty) and from frail/pre-frail to robust (reversal to robust). For both analysis, categories of progression to frailty or reversal of frailty were dependent variables. Baseline levels of social engagement/loneliness, as well as change in social engagement/loneliness, were independent variables. All covariates were adjusted in the models. Supplementary analyses were undertaken comparing the cohort characteristics of both study samples when they entered the study (start of study) and at two time points which forms the baseline and follow up of the present analyses (presented in Supplementary Table S4). All the analyses were conducted in SAS (version 9.4) and R (version 4.0.4).

Results

The study sample in the BRHS consisted of 715 men (Figure 1). At baseline, the mean age of participants was 77.96 years (SD 3.75). 376 participants (52.6%) were pre-frail and 66 (9.2%) were frail. In Health ABC, 1256 were included in the analysis, of whom 656 (52.2%) were female and 403 (32.1%) were African American. The mean age of participants at baseline was 78.07 years. (SD 2.77). 756 (60.2%) participants were classified as robust, 467 (37.2%) as pre-frail and 33 (2.6%) as frail. In both studies, the mean scores for social engagement at baseline were highest among the robust participants, followed by the pre-frail and were lowest among the frail participants. Mean scores for loneliness were highest among frail participants while lowest among robust participants. Other baseline characteristics of participants in the BRHS and Heath ABC are shown in Table 1.

Table 1. Baseline characteristics of participants in the BRHS (2010-12) and Health ABC (2002-03) included in this analysis

	BRHS			
	Robust	Pre-frail	Frail	Total
All, n (%)	273 (38.2%)	376 (52.6%)	66 (9.2%)	715 (100.0%)
Social engagement, mean (sd)	4.73 (1.76)	4.40 (1.68)	4.29 (1.66)	4.52 (1.71)
Loneliness, mean (sd)	0.98 (1.25)	1.27 (1.51)	2.02 (1.79)	1.23 (1.47)
Age at baseline, mean (sd)	76.15 (3.13)	77.40 (3.95)	77.82 (4.32)	76.96 (3.75)
Social class group, n (%)				
Non-manual	153 (56.0%)	219 (58.2%)	40 (60.6%)	412 (57.6%)
Manual	114 (41.8%)	148 (39.4%)	23 (34.9%)	285 (39.9%)
Missing	6 (2.2%)	9 (2.4%)	3 (4.6%)	18 (2.5%)
Current smoker, n (%)				
No	263 (96.3%)	366 (97.3%)	65 (98.5%)	694 (97.1%)
Yes	8 (2.9%)	9 (2.4%)	1 (1.5%)	18 (2.5%)
Missing	2 (0.7%)	1 (0.3%)	-	3 (0.4%)
Moderate to heavy alcohol consumption, n (%)				
No	259 (94.9%)	355 (94.4%)	66 (100.0%)	680 (95.1%)
Yes	12 (4.4%)	18 (4.8%)	-	30 (4.2%)
Missing	2 (0.7%)	3 (0.8%)	-	5 (0.7%)
History of CVD or diabetes, n (%)				
No	192 (70.3%)	221 (58.8%)	25 (37.9%)	438 (61.3%)
Yes	78 (28.6%)	150 (39.9%)	40 (60.6%)	268 (37.5%)
Missing	3 (1.1%)	5 (1.3%)	1 (1.5%)	9 (1.3%)
Obesity, n (%)				
No	234 (85.7%)	303 (80.6%)	47 (71.2%)	584 (81.7%)
Yes	39 (14.3%)	73 (19.4%)	19 (28.8%)	131 (18.3%)
History of depression, n (%)				
No	258 (94.5%)	355 (89.1%)	56 (84.9%)	649 (90.8%)
Yes	3 (1.1%)	10 (2.7%)	-	13 (1.8%)
Missing	12 (4.4%)	31 (8.2%)	10 (15.2%)	53 (7.4%)

	Health ABC			
	Robust	Pre-fail	Frail	Total
All, n (%)	756 (60.2%)	467 (37.2%)	33 (2.6%)	1256 (100.0%)
Social engagement, mean (sd)	6.85 (1.80)	6.33 (1.92)	5.58 (2.08)	6.62 (1.88)
Loneliness, mean (sd)	0.28 (0.57)	0.34 (0.66)	0.61 (0.66)	0.31 (0.61)
Age at baseline, mean (sd)	77.80 (2.66)	78.40 (2.87)	79.67 (2.81)	78.07 (2.77)
Gender, n (%)				
Male	361 (47.8%)	223 (47.8%)	16 (48.5%)	600 (47.8%)
Female	395 (52.3%)	244 (52.3%)	17 (51.5%)	656 (52.2%)
Ethnicity, n (%)				
White	540 (71.4%)	291 (62.3%)	22 (66.7%)	853 (67.9%)
African American	216 (28.6%)	176 (37.7%)	11 (33.3%)	403 (32.1%)
Education, n (%)				
Less than high school	121 (16.0%)	98 (21.0%)	12 (36.4%)	231 (18.4%)
High school graduate	240 (31.8%)	136 (29.1%)	9 (27.3%)	385 (30.7%)
Post-secondary	394 (52.1%)	232 (49.7%)	12 (36.4%)	638 (50.8%)
Missing	1 (0.1%)	1 (0.2%)	-	2 (0.2%)
History of CVD or diabetes, n (%)				
No	562 (74.3%)	324 (69.4%)	23 (69.7%)	909 (72.4%)
Yes	194 (25.7%)	143 (30.6%)	10 (30.3%)	347 (27.6%)
Obesity, n (%)				
No	592 (78.3%)	339 (72.6%)	19 (57.6%)	950 (75.6%)
Yes	164 (21.7%)	128 (27.4%)	14 (42.4%)	306 (24.4%)
History of depression, n (%)				
No	618 (81.8%)	339 (72.6%)	15 (45.5%)	972 (77.4%)
Yes	138 (18.3%)	128 (27.4%)	18 (54.6%)	284 (22.6%)

Transitions of frailty status in the BRHS and Health ABC

Figure 2 shows the dynamic change of frailty status over time in the BRHS and Health ABC. In the BRHS, 123 (17.2%) participants remained robust during the follow-up period. Progression to pre-frail was observed in 126 (17.6%) robust participants and 131 (18.3%) robust/pre-frail participants developed frailty at follow-up. We also observed that 16 (2.2%) of participants improved their frailty status from frail to pre-frail, and 67 (9.4%) from frail/pre-frail to robust. A total of 46 (6.4%) participants were frail at both baseline and follow-up. In Health ABC, 230 (18.3%) robust participants became pre-frail, and 47 (37.4%, 8 robust and 39 pre-frail) participants became frail after 4 years of follow-up. In contrast, 154 (12.3%) pre-frail participants reversed their status to robust, and 16 (1.3%) frail participants became pre-frail. A total of 807 (64.0%) participants did not change frailty status, of whom 518 (41.2%) continued robust, 274 (21.8%) stayed pre-frail and 15 (1.2%) remained frail.

Associations of social engagement and loneliness with progression to pre-frailty and frailty

Table 2 shows the relative risk ratios (RRR) of progression to pre-frailty and frailty, compared to sustained robustness, according to baseline and change in social engagement and loneliness. In the

BRHS cohort, participants with a higher baseline score of social engagement had a decreased risk of becoming pre-frail or frail. One unit increase in the social engagement score at baseline was associated with a 21% (RRR 0.79 [95%CI 0.66 – 0.96]) lower risk of being pre-frail relative to sustained robust, and a 31% (RRR 0.69 [95%CI 0.55 – 0.85]) reduced risk of being frail (vs sustained robust). Participants who increased social engagement during the follow-up period also reduced their risk of becoming frail (RRR 0.73 [95%CI 0.59 – 0.90]). With respect to loneliness, a higher score at baseline (RRR 1.42 [95% CI 1.10 – 1.83]), as well as an increase in loneliness (RRR 1.50 [95%CI 1.18 – 1.90]) were associated with elevated risk of developing frailty at follow-up.

In Health ABC, there was a 44% relative risk reduction of becoming frail (vs being sustained robust) for each one unit increase in social engagement score at baseline (RRR 0.56 [95%CI 0.45 – 0.70]). In addition, an increase in social engagement during the follow-up was associated with lower risk of developing pre-frailty (RRR 0.86 [95% CI 0.77 – 0.97]) and frailty (RRR 0.51 [95%CI 0.41 – 0.63]). No significant association was found between loneliness (baseline or change in score) and progression to pre-frailty and frailty in Health ABC.

Table 2. Relative risk ratios (RRR) of progression to pre-frailty and frailty according to baseline and change in social engagement and loneliness, compared with sustained robustness

BRHS						
	Progression to pre-frailty vs Sustained robustness			Progression to frailty vs Sustained robustness		
	RRR	95% CI	p value	RRR	95% CI	p value
Social engagement (n = 338)						
Baseline	0.79	(0.66 - 0.96)	0.018	0.69	(0.55 - 0.85)	0.0005
Change	0.87	(0.72 - 1.06)	0.17	0.73	(0.59 - 0.90)	0.0040
Loneliness (n = 323)						
Baseline	1.13	(0.88 - 1.46)	0.34	1.42	(1.10 - 1.83)	0.0074
Change	1.27	(1.01 - 1.59)	0.044	1.50	(1.18 - 1.90)	0.0009
Health ABC						
	Progression to pre-frailty vs Sustained robust			Progression to frailty vs Sustained robust		
	RRR	95% CI	p value	RRR	95% CI	p value
Social engagement (n = 795)						
Baseline	0.92	(0.83 - 1.02)	0.11	0.56	(0.45 - 0.70)	<0.0001
Change	0.86	(0.77 - 0.97)	0.013	0.51	(0.41 - 0.63)	<0.0001
Loneliness (n = 787)						
Baseline	1.35	(0.95 - 1.92)	0.089	1.74	(0.98 - 3.09)	0.059
Change	1.27	(0.96 - 1.68)	0.096	1.47	(0.91 – 2.39)	0.12

Note. In BRHS, covariates including age, social class group, smoking, alcohol intake, history of CVD or diabetes, obesity, and history of depression were adjusted. In Health ABC, covariates including age, gender, **ethnicity**, educational attainment, history of CVD and diabetes, obesity, and history of depression were adjusted.

Associations of social engagement and loneliness with reversal to pre-frailty and robust status

Tables 3 presents the RRRs for participants who reverse their frail status to pre-frail or robust status relative to those remaining frail, according to baseline and change in social engagement and loneliness scores. In the BRHS, pre-frail and frail participants who increased their social engagement during follow-up were more likely to become robust (RRR 1.71 [95%CI 1.18 – 2.50]). For those who experienced a higher level of loneliness at baseline and increased loneliness during follow-up, their probability of reversal of their frailty status from frail to pre-frail (baseline: RRR 0.51 [95%CI 0.29 – 0.91]; change: RRR 0.49 [95%CI 0.28 – 0.86]) and from frail/prefrail to robust (baseline: RRR 0.37 [95%CI 0.23 – 0.60]; change: RRR 0.57 [95% CI 0.37 – 0.87]) was roughly half as likely.

In Heath ABC, we also observed beneficial effects of social engagement on improving frailty status. Increasing social engagement during follow-up significantly increased the probability of reversing frailty status from frail to pre-frail (RRR 2.14 [95%CI 1.24 – 3.68]). In addition, participants who scored higher for social engagement at baseline (RRR 1.63, 95%CI 1.08 – 2.47) or increased social engagement during follow-up (RRR 1.79, 95%CI 1.17 – 2.74) were more likely to reverse their frailty status to robust. There were no significant effects of loneliness on reversal of frailty status.

Table 3. Relative risk ratios (RRR) of reversion to pre-frailty and robust status according to baseline and change of social engagement and loneliness, compared with persistent frailty

BRHS						
	Reversal to pre-frailty vs Persistent frailty			Reversal to robust vs Persistent frailty		
	RRR	95% CI	p value	RRR	95% CI	p value
Social engagement (n = 123)						
Baseline	0.93	(0.58 - 1.50)	0.78	1.38	(0.96 – 2.00)	0.086
Change	1.34	(0.85 - 2.10)	0.20	1.71	(1.18 - 2.50)	0.0050
Loneliness (n = 118)						
Baseline	0.51	(0.29 - 0.91)	0.021	0.37	(0.23 - 0.60)	<0.0001
Change	0.49	(0.28 - 0.86)	0.013	0.57	(0.37 - 0.87)	0.0085
Health ABC						
	Reversal to pre-frailty vs Persistent frailty			Reversal to robust vs Persistent frailty		
	RRR	95% CI	p value	RRR	95% CI	p value
Social engagement (n = 187)						
Baseline	1.50	(0.89 - 2.53)	0.13	1.63	(1.08 – 2.47)	0.020
Change	2.14	(1.24 - 3.68)	0.0062	1.79	(1.17 - 2.74)	0.0071
Loneliness (n = 187)						
Baseline	1.69	(0.45 - 6.40)	0.44	0.76	(0.26 - 2.21)	0.61
Change	1.40	(0.49 - 4.04)	0.53	0.68	(0.28 - 1.63)	0.39

Note. In BRHS, covariates including age, social class group, smoking, alcohol intake, history of CVD or diabetes, obesity, and history of depression were adjusted. In Heath ABC, covariates including age, gender, **ethnicity**, educational attainment, history of CVD and diabetes, obesity, and history of depression were adjusted.

Discussion

This study examined frailty trajectories and their associations with both social engagement and loneliness among community-dwelling older adults from two longitudinal studies from the UK and the USA. We found that around 36% of the sample from the BRHS in the UK, and 22% from Health ABC in the USA experienced worsening in frailty during follow-up of approximately 8 years and 4 years, respectively. Over the same time period, about 12% participants from the BRHS and 14% from Health ABC experienced an improvement in frailty status. These results indicate that although frailty is a distinctive health state related to the ageing process, it is not an inevitable part of ageing and is potentially reversible. Among individuals who experienced improvements in frailty, most (76% in BRHS; 90% in the Health ABC) moved from pre-frail to robust status, which indicates that the potential for improvement is greater in the earlier stage of frailty development.

In both cohorts, we found baseline levels of, as well as change in social engagement were associated independently with progression to frailty. This finding is consistent with previous studies, and provides additional evidence that being socially active in later life could attenuate the risk of developing frailty.^{26,31,36} One explanation for this association is that individuals who are socially engaged and connected are more likely to have healthier behaviours, probably due to the influence of friends and loved ones who support them to adopt a healthy lifestyle. Besides, having multiple social ties provides more sources of information, and thus increase likelihood to receive wider support and access to appropriate health care.³⁷⁻⁴¹ In the BRHS, we found that a higher score for loneliness at baseline predicted risk of frailty over 8 years, which suggests that the deleterious effect of loneliness on physical frailty persists over time. In addition, an increase in loneliness can also elevate the risk of becoming frail. Feeling lonely is itself a stressor that can cause anxiety, depression and hostility. Such negative affects and reactivity would promote chronic elevations in the physical system (e.g. elevated vascular activation), increase delays in seeking care and decreasing medical compliance and health care utilisation. Furthermore, loneliness can contribute to frailty through diminishing healthy behaviours such as poor nutrition, less exercise and fragmented sleep.^{18,42-45}

In addition to progression to frailty, this study also found significant effects of social engagement and loneliness on the reversal of frailty. For older adults who were already pre-frail or frail, increased social engagement was associated with frailty reversal in both cohorts. This result further confirms the beneficial effects of social engagement in improving frailty among older adults.⁴⁶ Moreover, we found that older adults in the BRHS who had a high level of loneliness at baseline, and those who experienced an increase in loneliness were less likely to recover from frailty. These associations were observed in both studies of community-dwelling older adults in the USA and UK, providing some consistency and robustness to the findings. Despite cultural differences and differences in terms of healthcare, the results were mostly consistent in both study populations. Collectively, our study findings point to the importance of social engagement in preventing and improving frailty among older adults.

The strengths and limitations of this study need to be considered. **A key strength of this study is the assessment of prospective associations of both quantitative and qualitative aspects of social connections with frailty through measures of both social engagement and loneliness in two distinct population cohort studies. Undertaking epidemiological investigations in these two cohort helps to assess consistency (or reproducibility), which is a key criterion to assess associations in epidemiological studies. In testing the association in the two study samples, we also provide findings on longitudinal associations between social engagement and frailty, using valid and reliable measures of exposures and outcomes. The measures of social engagement and frailty used are the same in the two studies.** Another strength is the investigation of the dynamic nature of social connections and frailty, and changes in these measures over time. A potential limitation of this study

is the generalisability of the findings. The design features of the cohorts meant that the BRHS consisted of White British men only and Health ABC recruited White and African-American men and women living in only two areas (Pittsburgh and Memphis) in the USA. Future research using larger population-based studies, particularly with greater representation from women and other ethnic minorities is needed to better understand the association between social connections and frailty among diverse populations of older adults. Besides, like many longitudinal cohort studies of older adults, this study inevitably suffered from survival bias. Participants who were younger and healthier were more likely to attend the follow-up of the studies. In the BRHS, participants in the present analyses, compared to those who withdrew or died before our study period, were younger and healthier. A similar pattern was observed in the Health ABC Study (Supplementary Table S4). Although survival bias was inevitable, these cohort studies of older adults offered the opportunity to examine the role of social connections in frailty among older age. This survival bias, if anything, might have led to a slight underestimation of the association between social connections and frailty, as surviving participants tended to be healthier. In Health ABC, loneliness was measured by a single item question, which may have limited content validity and sensitivity. This may explain the absence of an association between loneliness and frailty in that cohort. Furthermore, although our studies attempted to adjust for several confounders, information on some factors (e.g. smoking and alcohol used) in the Health ABC was unavailable. The possibility of residual confounding cannot be totally excluded. Additionally, previous studies have suggested that the relationship between social connections and frailty could be bidirectional.^{13,30} Although our study was longitudinal in design and found that social connections at baseline were associated with frailty at follow-up, which could potentially support causal relationships, the possibility that frailty, conversely, could influence social connections, was not tested in this study. Future longitudinal studies examining these associations in both directions would strengthen our understanding about the links between social connections and frailty in older adults.

Frailty has been recognised as an emerging public health issue among older adults.⁴⁷ Campaigns across countries have raised awareness to reduce the burden of frailty.⁴⁸⁻⁵¹ Notably, the National Health Service (NHS) in England has introduced routine frailty identification for patients aged 65 years and over registered in the GP system.⁵² To date, interventions on physical exercise and nutrition have been shown to be the most effective in improving frailty.⁵²⁻⁵⁴ Although an increasing number of studies highlight the potentially important role of social connections in frailty, intervention studies targeting these issues are limited.¹³ The issues of social isolation and loneliness have not been given sufficient attention in intervention studies, strategies or action plans for preventing frailty in older adults. Our findings which show that social engagement and loneliness were associated with the progression as well as reversal of frailty, suggest that it could be potentially important for health and social care professionals to consider assessing social ties, social activities and perceived loneliness along with identification of frailty risk. Population-based intervention strategies such as enhancing social connections and building age-friendly communities that provide opportunities for social interactions among older adults could contribute to reducing the burden of frailty.

Although frailty is a common condition in ageing populations, development of frailty is manageable, preventable and potentially reversible. This study provides evidence that social inactivity and loneliness are potentially important factors that increase the risk of developing frailty as well as hinder its reversal. Increasing social engagement and reducing loneliness among older adults could be beneficial in reducing the burden of frailty. Findings from this study, together with other related studies, highlight the importance of considering social connections as a crucial and modifiable factor in interventions to promote health ageing. Further observational and intervention studies are needed to examine this further.

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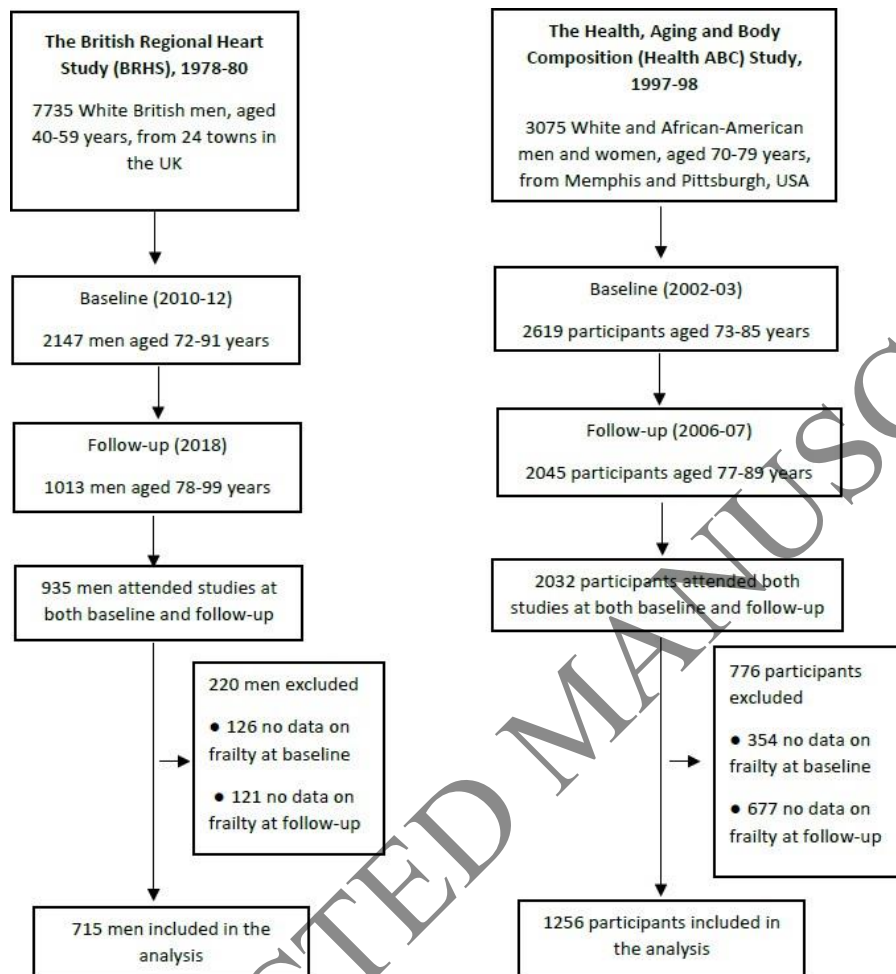


Figure 1: Profiles of the British Regional Heart Study (BRHS) and the Health, Ageing and Body Composition (Health ABC) Study samples in this analysis

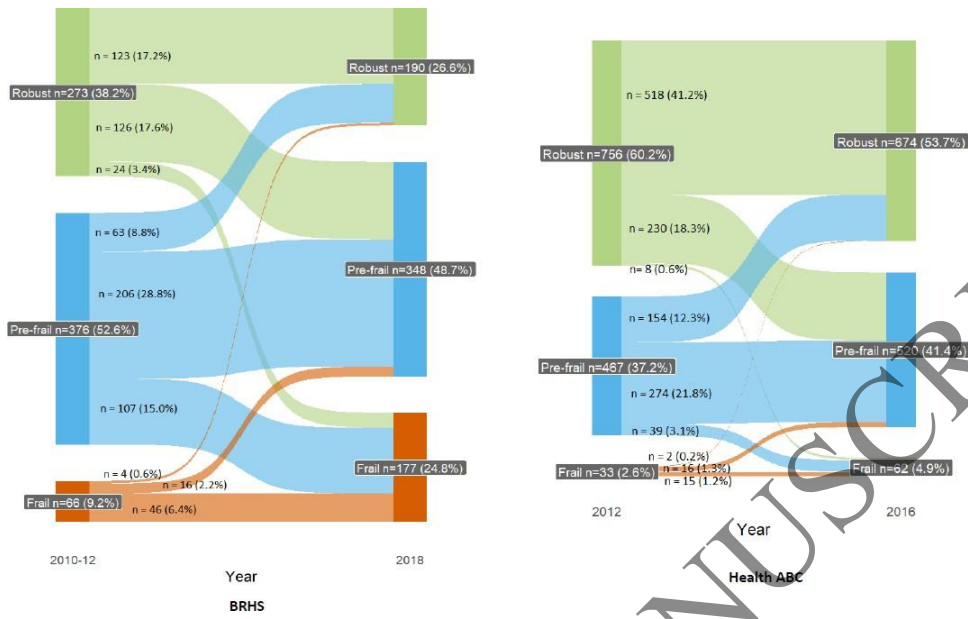


Figure 2. Changes in the frailty stages over time

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