Bidirectional Longitudinal Association between Back Pain and Loneliness in Later Life: Evidence from English Longitudinal Study of Ageing

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Running title:
Abstract

**Background:** This study examined the bidirectional and temporal-ordinal relationship between loneliness and back pain.

**Methods:** Data from 7,730 participants in waves 6 (2012–2013), 7 (2014–2015), and 8 (2016–2017) of the national English Longitudinal Study of Ageing were analyzed. Back pain was graded on a scale of 0–10 (0, no discomfort; 10, unbearable pain). Loneliness was measured using the Revised University of California Los Angeles Loneliness Scale. A targeted minimum loss-based estimator was used to examine the bidirectional longitudinal associations between back pain and loneliness.

**Results:** No loneliness in waves 6 and 7 (relative risk [RR]=0.76; 95% confidence interval [CI], 0.61–0.94), no loneliness in wave 6 but loneliness in wave 7 (RR=0.58; 95% CI, 0.50–0.68), and loneliness in wave 6 but not in wave 7 (RR=0.69; 95% CI, 0.57–0.86) were associated with significant risk reductions of back pain in wave 8 compared with the scenario of loneliness in waves 6 and 7. Mild back pain in wave 6 but moderate back pain (RR=0.55; 95% CI, 0.35–0.86) or severe back pain in wave 7 (RR=0.49; 95% CI, 0.34–0.72) showed a significant risk reduction of loneliness in wave 8 compared with severe back pain in waves 6 and 7.

**Conclusion:** Loneliness may be a risk factor for back pain, and back pain may be a risk factor for loneliness. The results of this study will inform the development of more effective interventions for loneliness and back pain.

**Key Words:** Back pain, Loneliness, Longitudinal studies
INTRODUCTION

Back pain is a common cause of physical disability\textsuperscript{1-3}) and affects a large proportion of the general population.\textsuperscript{4,5}) A systematic review reported that the prevalence of back pain tends to be higher in older adults.\textsuperscript{4}) Moreover, the healthcare costs associated with back pain are high, particularly in high-income countries, at an estimated $87.6 billion in the United States,\textsuperscript{6}) €740 million in Sweden,\textsuperscript{7}) and ¥1.2 trillion ($10.6 billion, €9.3 billion) in Japan.\textsuperscript{8}) Therefore, back pain prevention and interventions are essential from a public health perspective.

Loneliness is a risk factor for various health outcomes, including physical and cognitive decline, mental illness, and cardiovascular disease.\textsuperscript{9,10}) It is defined as a state in which individuals experience a deeply felt lack of social contact or belongingness or a sense of isolation.\textsuperscript{9}) Loneliness is also a risk factor for musculoskeletal pain.\textsuperscript{11,12}) However, the relationship between loneliness and pain may be bidirectional,\textsuperscript{13,14}) in which loneliness-induced stress may increase pain, which contributes to loneliness by limiting social interaction.\textsuperscript{15,16}) Previous studies examining the longitudinal relationship between loneliness and pain generally analyzed these factors separately, making it difficult to determine the relative importance of the two temporal orders.\textsuperscript{13,15}) Loeffler et al.\textsuperscript{14}) demonstrated a bidirectional longitudinal association between baseline loneliness and pain in an older population. Baseline loneliness predicted pain in the fourth follow-up year, and vice versa. In contrast, Yu et al.\textsuperscript{17}) did not identify any significant longitudinal interaction between loneliness and pain; that is, pain did not predict future loneliness and vice versa. This discrepancy between studies may be due to the time-varying nature of loneliness and back pain. Loeffler et al.\textsuperscript{14}) examined the association between baseline exposure and outcome at the fourth follow-up year and, thus, did not account for temporal degeneration of exposure over 4 years. Although Yu et al.\textsuperscript{17}) adjusted for the time-varying nature of pain, they did not consider the time-varying nature of social isolation. In
general, longitudinal observational studies examining the effects of exposures measured only at baseline on the outcome of interest are likely to underestimate time-varying exposures.\textsuperscript{18)} Loneliness and back pain status can change over time. For example, loneliness increased by 31.7\% after 4 years among people aged \( \geq 60 \) years.\textsuperscript{19)} Another study that compared the prevalence of social isolation in Japan and England reported an increase in prevalence over 6 years.\textsuperscript{20)} During the coronavirus disease 2019 (COVID-19) pandemic, loneliness was reported to increase in older populations after approximately 6 months because of limited social interactions resulting from physical distance restrictions.\textsuperscript{21)} Another systematic review reported that the COVID-19 pandemic increased the prevalence and severity of back pain.\textsuperscript{22)} Additionally, approximately 6\% of older individuals who were free from back pain reported new-onset back pain in the fourth year of a follow-up survey among older individuals who were free from back pain.\textsuperscript{23)} Moreover, exercise therapy reduced back pain severity during the first year of follow-up.\textsuperscript{24)} Therefore, from the public health perspective, changes in “exposure” status should be evaluated as the outcome of interest. Therefore, to address the limitations of previous studies, the present study examined the bidirectional and temporal relationships between loneliness and back pain using a single nationally representative population survey conducted in England.

**MATERIALS AND METHODS**

This study conducted two statistical analyses to examine the bidirectional and temporal\textsuperscript{25)} relationships between loneliness and back pain using back pain (Study 1) and loneliness (Study 2) as the outcome, respectively.

**Study Population**
Data from waves 6 (2012–2013), 7 (2014–2015), and 8 (2016–2017) of the national English Longitudinal Study of Aging (ELSA) survey were analyzed. The survey began in 2002 and is conducted every 2 years among men and women aged >50 years residing in England.\textsuperscript{26} The analysis included 7,730 participants who were eligible to be polled in all three waves. Of the 7,730 participants, 942 were excluded because of missing baseline variables—educational attainment (n=30), equalized household income (n=123), back pain (n=6), loneliness (n=722), longstanding illness (n=1), arthritis (n=5), osteoporosis medication (n=1), and depressive symptoms (n=54). Participants who responded to the baseline survey but did not respond to waves 7 or 8 and those with missing variables from waves 7 and 8 were also excluded. In Study 1, after excluding 2,900 participants, the main analysis included 4,830 participants (mean age at baseline, 67.2±8.9 years). Similarly, after excluding 3,246 participants, the main analysis in Study 2 included 4,484 participants (mean age at baseline, 67.1±8.8 years) (Fig. 1).

**Back Pain**

The participants were asked the following questions to gauge their level of back pain: “Are you frequently bothered by pain?” If the participants answered “Yes,” they were then asked, “In which parts of the body do you feel pain?” “Back” responses were interpreted as those indicating back pain. The participants were also asked to rate the severity of their pain by answering the following question: “How would you rate your pain if you were walking on a flat surface? Please rate your pain from 0 to 10 for each of the following, where 0 is no pain and 10 is severe or excruciating pain or “as bad as you can imagine” (i.e., the numerical rating scale, [NRS]).\textsuperscript{27} As previously described, participants who did not report “back” pain were regarded as having an NRS of 0.\textsuperscript{28} The NRS has been previously validated.\textsuperscript{27}

As no definitive cutoff value for pain severity has yet been determined,\textsuperscript{29} given the clinical utility of assessing the detailed impacts of pain severity on the outcomes, we defined the
following categories of back pain: none (NRS=0), mild (NRS=1 to 3), moderate (NRS=4 to 6), and severe (NRS ≥7) in Study 2. While a previous study reported that an NRS score of 5 or 6 is commonly used as the cutoff value for moderate pain, we used a cutoff score of 6 in Study 1 because it is associated with disability.

**Loneliness**

Loneliness was measured using a short form consisting of three items from the Revised University of California Los Angeles (UCLA) Loneliness Scale. Each item is rated on a scale of hardly ever (1 point), sometimes (2 points), or often (3 points), with a score of ≥6 indicating loneliness. Cronbach’s alpha was calculated to assess the internal consistency of the reliability. Its validity has been examined previously.

**Covariates**

Age (continuous), sex (binary; male vs. female), educational attainment (continuous), race (binary; white vs. other), equalized household income (continuous), depressive symptoms (binary; no vs. yes; based on the Center for Epidemiologic Studies Depression Scale), exercise at least once weekly (binary; no vs. yes), longstanding illness (binary; no vs. yes), arthritis (binary; no vs. yes), osteoporosis medication (binary; no vs. yes), physical therapy (PT) or occupational therapy (OT) interventions in the past 3 months (binary; no vs. yes), and participation in exercise classes (binary; no vs. yes) were associated with back pain and loneliness and were used as covariates. PT or OT and exercise interventions were considered potential confounding factors in Study 1 but not in Study 2 according to previous studies.

**Statistical Analysis**
The targeted minimum loss-based estimator (TMLE) was used to assess time-variant exposure to outcome risk.\textsuperscript{37} We used the SuperLearner package, an ensemble machine learning method, to select the optimal algorithm for the exposure and outcome models. The candidate estimators for the SuperLearner algorithms are generalized linear models, gradient boosting models, and neural networks.\textsuperscript{38-41} Changes in hypothetical exposure in waves 6 and 7 were assessed for their impact on outcome risk in wave 8. These models were compared to calculate the relative risk (RR) and 95% confidence interval (CI). In Study 1, four scenarios were set up based on the presence or absence of hypothetical loneliness in waves 6 and 7. Each estimate was compared with the loneliness scenario for both waves 6 and 7, and the RR for back pain in wave 8 and its confidence interval were calculated. The same analysis was performed using two different sensitivity analyses with different cutoff values for the definition of back pain. The cutoff values were ≥4 and ≥5. In Study 2, 16 scenarios were established based on hypothetical back pain changes in waves 6 and 7. Each estimate was compared with the scenario of severe back pain in both waves 6 and 7, and the RR for loneliness in wave 8 and its confidence interval were calculated. R software (version 4.2.2 for Windows) was used for all statistical analyses. The National Research and Ethics Committee approved all ELSA waves, and all participants provided informed consent—wave 6 (No. 11/SC/0374), wave 7 (No. 13/SC/0532), and wave 8 (No. 15/SC/0526). We applied to the UK Data Service (https://beta.ukdataservice.ac.uk/) to obtain permission to access ELSA data. As all ELSA data were anonymous and freely accessible from the UK Data Service, the need for ethical approval was waived for this study.

This study complied the ethical guidelines for authorship and publishing in the \textit{Annals of Geriatric Medicine and Research}.\textsuperscript{42}

\textbf{RESULTS}
Study 1

Table 1 shows the baseline characteristics of back pain based on the follow-up survey (wave 8). In the follow-up study, participants who reported back pain were older, were more likely to be female, had lower levels of education and income, had more comorbidities, had a history of arthritis, and had lower physical activity levels compared with those who did not report back pain. Moreover, 29.8% of the participants with back pain experienced loneliness at baseline (Supplementary Table S1). The Cronbach’s alpha across the UCLA Loneliness Scale in Study 1 was 0.83, indicating good internal consistency.

The results of the TMLE model are shown in Fig. 2. The scenarios with no loneliness in waves 6 and 7 (RR=0.76; 95% CI, 0.61–0.94; p=0.013), no loneliness in wave 6 but loneliness in wave 7 (RR=0.58; 95% CI, 0.50–0.68; p<0.001), and loneliness in wave 6 but no loneliness in wave 7 (RR=0.69; 95% CI, 0.57–0.86; p<0.001) all showed a significant risk reduction of back pain compared with the scenario with loneliness in waves 6 and 7.

The sensitivity analysis results are shown in Supplementary Figs. S1 and S2. Analysis with reclassified cutoff values for moderate/severe back pain revealed a similar trend.

Study 2

Table 2 shows the baseline characteristics according to loneliness in the follow-up survey (wave 8). Based on the follow-up survey, the participants who reported loneliness were more likely to be female, had lower levels of education and income, had more comorbidities and arthritis, and participated less in exercise classes than those who did not report loneliness. Among participants with loneliness at baseline, 8.1%, 10.4%, and 7.7% had mild, moderate, and severe back pain, respectively (Supplementary Table S2). The Cronbach’s alpha across the UCLA Loneliness Scale in Study 2 was 0.84, indicating good internal consistency.
The results of the TMLE model are shown in Fig. 3. The scenarios with no back pain in waves 6 and 7 (RR=0.64; 95% CI, 0.49–0.85; p<0.005), no back pain in wave 6 but severe back pain in wave 7 (RR=0.59; 95% CI, 0.48–0.73; p<0.001), mild back pain in wave 6 but moderate back pain in wave 7 (RR=0.55; 95% CI, 0.35–0.86; p<0.01), mild back pain in wave 6 but severe back pain in wave 7 (RR=0.49; 95% CI, 0.34–0.72; p<0.001), moderate back pain in waves 6 and 7 (RR=0.57; 95% CI, 0.35–0.93; p=0.024), and severe back pain in wave 6 but mild back pain in wave 7 (RR=0.51; 95% CI, 0.32–0.83; p=0.007) showed significant risk reductions in reported loneliness compared with the scenario with severe back pain in waves 6 and 7. The scenarios with moderate back pain in wave 6 but severe back pain in wave 7 (RR=1.30; 95% CI, 1.04–1.62; p=0.021) showed a significant risk increase in reported loneliness compared with the scenario with severe back pain in waves 6 and 7. No significant differences were observed in the other scenarios.

DISCUSSION

This study analyzed ELSA data to examine the bidirectional and temporal relationships between loneliness and back pain. The results of Study 1 showed that a single period of no loneliness during the two study periods was associated with the risk of back pain at the 4-year follow-up (wave 8). The results of Study 2 showed significant associations with back pain in some scenarios, although it was also a risk factor for loneliness. The results of Study 1 implied that loneliness could be a risk factor for back pain, which is consistent with the findings of a previous study on the relationship between loneliness and pain.9,14,15 The relative risk of back pain differed between the no-loneliness scenario in wave 6 and the loneliness scenario in wave 7 (RR of 0.58), and the loneliness scenario in wave 6 but the no-loneliness scenario in wave 7 (RR of 0.69). These results suggest that even when
participants experienced loneliness at some point, a period without loneliness could alleviate the onset of back pain because of the reminder effect. Therefore, the early detection and implementation of interventions for loneliness may prevent the onset of back pain. The results from Study 1 also indicated that interventions to prevent persistent loneliness could reduce the burden of feeling disabled and the medical costs associated with back pain diagnosis.

Chronic stress response over-activation can be caused by loneliness, which can lead to pain. Stress and pain are associated because neurotransmitters released by stress affect nociceptors. Long-term exposure to stress reorganizes regions of the brain related to pain, while stress-related metabolic changes affect peripheral nerve function and pain transmission. In addition, neurotransmitters such as serotonin are involved in both depression and pain, and loneliness-related depression may lead to pain. According to one theory, social isolation affects brain regions that process physical pain. These findings support the association between loneliness and back pain. The results of the present study suggest that loneliness may reduce the burden of disability and increase medical costs associated with back pain.

In contrast, Study 2 identified a significant association between changes in back pain and the prevalence of loneliness. This finding is contrary to those of a report by Yu et al. However, the previous study did not consider the time-varying nature of exposure. Moreover, the definitions of pain and loneliness and the statistical analysis methods used in the present study differ from those used in previous studies. Previous studies examining the association between chronic pain and loneliness generally targeted widespread pain, whereas the present study focused on back pain. In addition, previous analyses did not distinguish between moderate and severe pain, contrary to the present study. Because of these differences, further studies are needed to examine multiple cases using different analytical methods. In the present study, the risk of loneliness tended to decrease in many severe back pain scenarios in waves 6 and 7. For
example, the scenarios with no back pain in waves 6 and 7 (RR=0.64; 95% CI, 0.49–0.85; p<0.005), mild back pain in wave 6 and moderate back pain in wave 7 (RR=0.55; 95% CI, 0.35–0.86; p<0.01), and moderate back pain in waves 6 and 7 (RR=0.57; 95% CI, 0.35–0.93; p=0.024) showed significant reductions in reported loneliness compared with the severe back pain scenarios in waves 6 and 7. Back pain decreases with increased social participation, and decreased social participation is a factor contributing to feelings of loneliness. These findings suggest that back pain could be a risk factor for loneliness by limiting social participation. However, the moderate back pain scenario in wave 6 the but severe back pain scenario in wave 7 (RR=1.30; 95% CI, 1.04–1.62; p=0.021) showed a significant risk increase in reported loneliness compared with the severe back pain scenario in waves 6 and 7. Although no significant differences were observed, a similar trend was observed in the severe back pain scenario in wave 6 but moderate back pain scenario in wave 7 (RR=1.24; 95% CI, 0.94–1.65; p=0.13). This suggests that moderate-to-severe temporal changes may be risk factors for loneliness. Therefore, future studies are needed to quantitatively evaluate the differences in the impact of back pain severity on social participation.

Poor social relationships and low social acceptance are predictors of chronic pain. In addition, participation in cultural activities such as visiting museums and art galleries can reduce the risk of developing pain in older adults. These findings suggest an association between psychosocial activity and pain. Compared with mild/moderate back pain, severe back pain may have acted as a disincentive for social participation and activity in the present study. Interventions for back pain may not only improve back pain but also improve social interventions, such as increasing social participation and exercise, which are effective interventions for loneliness.

This study has several limitations. First, unknown confounders were possible owing to the longitudinal observational study design rather than a randomized controlled trial. Second,
participant dropout may have contributed to a selection bias. This study included only participants with no missing data in waves 6–8. Of the 7,730 participants, 2,900 dropped out in Study 1, and 3,246 dropped out in Study 2. Third, we defined the cutoff back pain values differently between Studies. In Study 1, we defined back pain as NRS ≥6. In Study 2, we defined back pain categories (NRS 0, none; NRS 1–3, mild; NRS 4–6, moderate; and NRS ≥7, severe); however, a clear cutoff value for these categories is lacking. Therefore, a change in the cutoff value could have affected the results. Fourth, we could not distinguish between participants with acute and chronic back pain because of the imprecise recall period. Therefore, the prevalence of back pain may have been underestimated or overestimated. Fifth, the NRS used in this study may represent disabling pain, rather than general back pain at rest. Chronic pain that interferes with daily life ranges from short-term episodes with low degrees of disability to long-term syndromes with multiple physical and psychological symptoms and severe daily living restrictions. From a public health perspective, the reality of disabling pain in older populations must be understood across this spectrum. Sixth, we could not distinguish between participants who answered “often” to all questions at baseline (9 points) but “rarely or never” to all questions in the intermediate wave (3 points) and those who answered “sometimes” to all questions at baseline (6 points) but “sometimes” to two questions in the next wave and “sometimes” to one question in the “very little or none at all” (5 points).

In conclusion, this study analyzed ELSA data to examine the bidirectional and temporal associations between back pain and loneliness. These results suggest that loneliness is a risk factor for back pain. Moreover, mild-to-moderate back pain may reduce the risk of loneliness. Interventions for loneliness are effective in reducing the risk of back pain, while interventions for back pain may reduce the risk of loneliness.

ACKNOWLEDGMENTS
We thank all the study participants and the UK Data Service.

CONFLICT OF INTEREST

The researchers claim no conflicts of interest.

FUNDING

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AUTHOR CONTRIBUTIONS

Conceptualization, YS, TS, MT, MM, TI; Data curation, YS, TI; Funding acquisition, TI; Investigation, TI; Methodology, YS, TI; Project administration, YS, TI; Supervision, TI; Writing–original draft, YS; Writing–review & editing: TS, MT, MM, TI.

SUPPLEMENTARY MATERIALS

Supplementary materials can be found via https://...

REFERENCES


https://doi.org/10.2130/jjesp.22.99


Table 1. Baseline characteristics of the study participants who responded to all three waves, stratified according to back pain at follow-up (England, 2012–2014–2016)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Back pain at the 4-year follow-up</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Did not report (n=4,253)</td>
<td>Reported (n=577)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>66.5±8.3</td>
<td>68.3±8.6</td>
</tr>
<tr>
<td>Sex, female</td>
<td>2,264 (53.2)</td>
<td>403 (69.8)</td>
</tr>
<tr>
<td>Ethnicity, White</td>
<td>4,164 (97.9)</td>
<td>561 (97.2)</td>
</tr>
<tr>
<td>Educational attainment (y)</td>
<td>11.6±1.7</td>
<td>10.9±1.5</td>
</tr>
<tr>
<td>Equalized household income (British pound)</td>
<td>428.0±561.2</td>
<td>311.9±194.8</td>
</tr>
<tr>
<td>Reported loneliness</td>
<td>767 (18.0)</td>
<td>174 (30.2)</td>
</tr>
<tr>
<td>Existing longstanding illness</td>
<td>2,099 (49.4)</td>
<td>478 (82.8)</td>
</tr>
<tr>
<td>Existing arthritis</td>
<td>1,222 (28.7)</td>
<td>377 (65.3)</td>
</tr>
<tr>
<td>No light physical activity at all</td>
<td>319 (7.5)</td>
<td>82 (14.2)</td>
</tr>
<tr>
<td>Osteoporosis medication</td>
<td>140 (3.3)</td>
<td>48 (8.3)</td>
</tr>
<tr>
<td>Depressive symptom</td>
<td>369 (8.7)</td>
<td>136 (23.6)</td>
</tr>
</tbody>
</table>

Values are presented as mean±standard deviation or number (%).
*T-test, **chi-squared test.
Table 2. Baseline characteristics of the study participants who responded to all three waves, stratified according to loneliness at follow-up (England, 2012–2014–2016)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Loneliness at the 4-year follow-up</th>
<th>P-value</th>
</tr>
</thead>
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<td></td>
<td>Did not report (n=3,708)</td>
<td>Reported (n=766)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>66.4±8.1</td>
<td>66.9±8.7</td>
</tr>
<tr>
<td>Sex, female</td>
<td>1,998 (53.9)</td>
<td>482 (62.1)</td>
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<tr>
<td>Ethnicity, White</td>
<td>3,636 (98.1)</td>
<td>755 (97.3)</td>
</tr>
<tr>
<td>Educational attainment (y)</td>
<td>11.6±1.7</td>
<td>11.2±1.6</td>
</tr>
<tr>
<td>Equalized household income (British pound)</td>
<td>430.0±535.4</td>
<td>359.3±586.7</td>
</tr>
<tr>
<td>Reported back pain</td>
<td></td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td>Mild</td>
<td>202 (5.4)</td>
<td>56 (7.2)</td>
</tr>
<tr>
<td>Moderate</td>
<td>226 (6.1)</td>
<td>80 (10.3)</td>
</tr>
<tr>
<td>Severe</td>
<td>143 (3.9)</td>
<td>75 (9.7)</td>
</tr>
<tr>
<td>Existing longstanding illness</td>
<td>1,874 (50.5)</td>
<td>496 (63.9)</td>
</tr>
<tr>
<td>Existing arthritis</td>
<td>1,161 (31.3)</td>
<td>307 (39.6)</td>
</tr>
<tr>
<td>No light physical activity at all</td>
<td>267 (7.2)</td>
<td>81 (10.4)</td>
</tr>
<tr>
<td>No participation in exercise classes</td>
<td>3,062 (82.6)</td>
<td>685 (88.3)</td>
</tr>
<tr>
<td>PT or OT interventions in the past 3 months</td>
<td>311 (8.4)</td>
<td>90 (11.6)</td>
</tr>
<tr>
<td>Osteoporosis medication</td>
<td>136 (3.7)</td>
<td>36 (4.6)</td>
</tr>
<tr>
<td>Depressive symptom</td>
<td>240 (6.5)</td>
<td>222 (28.6)</td>
</tr>
</tbody>
</table>

Values are presented as mean±standard deviation or number (%).
PT, physical therapist; OT, occupational therapist.
*T-test, **chi-squared test.
Fig. 1. Participants of Study 1 and Study 2.
Fig. 2. Results of the targeted minimum loss-based estimator model. The relative risk and 95% confidence interval (CI) for back pain in wave 8 are calculated from the hypothetical scenarios of loneliness changes in waves 6 and 7. Cutoff values for the definition of back pain were ≥6.
Fig. 3. Results of the targeted minimum loss-based estimator model. The relative risk and 95% confidence interval (CI) for loneliness in wave 8 are calculated from the hypothetical scenarios of back pain changes in waves 6 and 7.
**SUPPLEMENTARY MATERIALS**

**Table S1.** Characteristics of loneliness at baseline for study participants who responded to all three waves, stratified according to back pain at baseline (England, 2012–2014–2016)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Back pain at baseline</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Did not report (n=4,253)</td>
<td>Reported (n=577)</td>
</tr>
<tr>
<td>Loneliness status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No loneliness</td>
<td>3,547 (81.7)</td>
<td>342 (70.2)</td>
</tr>
<tr>
<td>Loneliness</td>
<td>796 (18.3)</td>
<td>145 (29.8)</td>
</tr>
</tbody>
</table>

Values are presented as number (%).

*Chi-squared test.

**Table S2.** Characteristics of back pain at baseline for study participants who responded to all three waves, stratified according to loneliness at baseline (England, 2012–2014–2016)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Loneliness at baseline</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Did not report (n=3,640)</td>
<td>Reported (n=844)</td>
</tr>
<tr>
<td>Back pain status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>3,079 (84.6)</td>
<td>623 (73.8)</td>
</tr>
<tr>
<td>Mild</td>
<td>190 (5.2)</td>
<td>68 (8.1)</td>
</tr>
<tr>
<td>Moderate</td>
<td>218 (6.0)</td>
<td>88 (10.4)</td>
</tr>
<tr>
<td>Severe</td>
<td>153 (4.2)</td>
<td>65 (7.7)</td>
</tr>
</tbody>
</table>

Values are presented as number (%).

*Chi-squared test.
**Fig. S1.** The results of the targeted minimum loss-based estimator model. The relative risk and 95% confidence interval (CI) for back pain in wave 8 are calculated from hypothetical scenarios of loneliness changes in waves 6 and 7. Cutoff values for the definition of back pain were ≥4.
Fig. 2. The results of the targeted minimum loss-based estimator model. relative risk and 95% confidence interval (CI) for back pain in wave 8 are calculated from hypothetical scenarios of loneliness changes in waves 6 and 7. Cutoff values for the definition of back pain were ≥5.