Association between internet exclusion and depressive symptoms among older adults: panel data analysis of five longitudinal cohort studies

Rui Yan,[a] Xinwei Liu,[b] Ruyue Xue,[a] Xiaoran Duan,[a] Lifeng Li,[a] Xianying He,[a] Fangfang Cui,[a] and Jie Zhao[a,c,*]

[a]Internet Medical and System Applications of National Engineering Laboratory, The First Affiliated Hospital of Zhengzhou University, Zhengzhou, Henan 450052, PR China
[b]Department of Breast Surgery, The First Affiliated Hospital of Zhengzhou University, Zhengzhou, Henan 450052, PR China
[c]Shanghai Artificial Intelligence Laboratory, Shanghai 200232, PR China

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Summary

Background Internet exclusion and depressive symptoms are prevalent phenomena among older adults; however, the association between internet exclusion and depressive symptoms remains limited. This study aims to investigate the association between internet exclusion and depressive symptoms among older adults from high-income countries (HICs) and low- and middle-income countries (LMICs).

Methods We conducted a comprehensive longitudinal, cross-cultural analysis, and the participants were adults aged 60 years and older from 32 countries participating in five nationally representative longitudinal cohort studies: the Health and Retirement Study (HRS), the English Longitudinal Study of Ageing (ELSA), the Survey of Health, Ageing and Retirement in Europe (SHARE), the China Health and Retirement Longitudinal Study (CHARLS), and the Mexican Health and Ageing Study (MHAS). Internet exclusion was defined as the self-reported absence from internet use. Depressive symptoms were evaluated using the Centre for Epidemiologic Studies of Depression scale (CES-D) or the Euro-Depression scale (Euro-D). These five cohorts, being heterogeneous, were respectively conducted with panel data analysis. Logistic regression, implemented within the generalized estimating equations framework, was used to examine the association between internet exclusion and the likelihood of experiencing depressive symptoms, adjusting for the causal-directed-acyclic-graph (DAG) minimal sufficient adjustment set (MSAS), including gender, age, education, labour force status, household wealth level, marital status, co-residence with children, residence status, cognitive impairment, and functional ability.

Findings Our study included a total of 129,847 older adults during the period from 2010 to 2020, with a median follow-up of 5 (2, 7) years. The pooled proportion of internet exclusion was 46.0% in HRS, 32.6% in ELSA, 54.8% in SHARE, 92.3% in CHARLS, and 65.3% in MHAS. Internet exclusion was significantly associated with depressive symptoms across all cohort studies: HRS (OR = 1.13, 95% CI 1.07–1.20), ELSA (OR = 1.22, 95% CI 1.11–1.34), SHARE (OR = 1.55, 95% CI 1.47–1.62), CHARLS (OR = 1.49, 95% CI 1.26–1.77), and MHAS (OR = 1.48, 95% CI 1.39–1.58). Moreover, internet exclusion was found to be associated with all dimensions of depression in the SHARE, MHAS, and ELSA cohorts (except for sleep and felt sad) cohorts.

Interpretation A considerable proportion of older adults experienced internet exclusion, particularly those in LMICs. Internet exclusion among older adults, irrespective of their geographic location in HICs or LMICs, was associated with a higher likelihood of experiencing depressive symptoms, which demonstrated the importance of addressing barriers to internet access and promoting active participation in the internet society among older adults.

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*Corresponding author. The First Affiliated Hospital of Zhengzhou University, 1 East Jianshe Road, Zhengzhou, Henan 450052, China.
E-mail address: zhaojie@zzu.edu.cn (J. Zhao).

Keywords: Internet exclusion; Depressive symptoms; Older adults; Cohort studies

Research in context

Evidence before this study

We conducted a comprehensive search on PubMed and Web of Science for English articles published from inception to September 1, 2023, using the terms (internet exclusion OR internet use OR internet access OR digital exclusion OR digital inclusion OR digital divide) AND (depressive symptoms OR depression) AND older adults. While this search yielded several relevant studies, the association between internet exclusion and depressive symptoms showed inconsistency. For example, Zhang et al. conducted a cross-sectional study in China, which indicated that internet use was associated with lower levels of depression. However, Xie et al. found that internet use increased the incidence of depressive symptoms among older adults in China. Additionally, Elliot et al. conducted a cross-sectional study in the United States and found no significant association between the use of information and communications technology and depressive symptoms. It is important to note that most of the evidence provided in these studies was limited to descriptive analyses using cross-sectional data. There is a lack of research investigating the association between internet exclusion and depressive symptoms among older adults on a global scale, including data from both low- and middle-income countries (LMICs) and high-income countries (HICs). Furthermore, the individual depressive symptoms may not be equivalent, and the contribution of internet exclusion to each specific depressive symptom remains unknown. Therefore, our study aims to comprehensively examine the association between internet exclusion and depressive symptoms among older adults, incorporating data from both HICs and LMICs. Additionally, we seek to investigate the association between internet exclusion and each individual depressive symptom.

Added value of this study

The present study included five comparative cohort studies (HRS, ELSA, SHARE, CHARLS, and MHAS), encompassing 129,847 participants from 32 countries, including both HICs and LMICs. To the best of our knowledge, this study represents the first longitudinal analysis examining the association between internet exclusion and depressive symptoms among older adults. Our results indicated a considerable proportion of older adults experiencing internet exclusion, particularly in LMICs. The key finding revealed a significant association between internet exclusion and depressive symptoms in both HICs and LMICs. Moreover, internet exclusion was found to be associated with most dimensions of depression.

Implications of all the available evidence

Experiencing internet exclusion poses a significant risk of depressive symptoms among older adults. Therefore, the implementation of internet inclusion strategies is crucial in promoting healthy ageing and reducing the prevalence of depressive symptoms among older populations.

Introduction

The global population is undergoing a rapid and continuous process of ageing. By the year 2030, it is projected that approximately one-sixth of the world's population will be aged 60 years or older.[1] Older adults often face challenges such as declining physical functioning and transitioning social roles, which can contribute to the development of negative emotions. Depressive symptoms are common psychological symptoms among older adults. A previous meta-analysis reported a substantial global prevalence rate of 35.1% for depressive symptoms among older adults.[2] Depressive symptoms were associated with various negative physical issues, including sleep disruptions, coronary heart disease, inflammatory responses, and physical pain.[3–5] If not treated early, the prolonged depressive states may worsen into a clinical depression and serious consequences as self-harm.[6] It is estimated that major depressive disorders will become the largest contributor of the global disease burden by 2030.[7] Therefore, the prevention, recognition, and treatment of depressive symptoms in older adults should be emphasized as an immediate global priority.[8]

The pace of internet development is comparable to the rapid growth in the size of the older adults, and there are 5.16 billion internet users worldwide in 2023, accounting for 64.4% of the global population.[9] However, population ageing has also resulted in a substantial number of internet excluded individuals. Internet exclusion refers to the unequal access to and limited capability of utilizing internet.[10,11] According to reports, individuals aged 60 and above constitute the main demographic of non-internet users.[12] Compared to younger individuals, older adults are less likely to actively engage with and utilize information and communications technologies (ICTs).[13] The absence of internet engagement also includes a range of valuable online services, such as health information, internet social events, and social networking or online shopping opportunities.[10] Previous research has shown that internet exclusion is also associated with decreased cognitive function, increased functional dependency, and diminished social well-being among older adults.[11,14,15] Furthermore, internet exclusion may contribute to feelings of loneliness, social isolation,

insecurity, and a disconnection from the contemporary world, thereby increasing the risk of depression among older adults, particularly during the Corona Virus Disease 2019 (COVID-19) pandemic.

However, the research examining the association between internet exclusion and depressive symptoms among older adults has yielded inconsistent findings. While some studies suggest a possible positive or negative association with depressive symptoms,[16–18] other research fails to establish a significant association.[15,19] It is also important to note that previous studies have predominantly used cross-sectional designs with limited sample sizes, which restricts the generalization of their findings. Additionally, due to the substantial variations in digitization levels across countries, the association between internet exclusion and depressive symptoms may differ between low- and middle-income countries (LMICs) and high-income countries (HICs), necessitating the exploration of databases encompassing multiple countries worldwide. Moreover, it remains unclear whether the association between internet exclusion and depressive symptoms varies across different groups characterized by confounding factors, and which sub-populations are more susceptible to the influence of internet exclusion on depressive symptoms. Finally, in epidemiological research, most measures of depression are based on the threshold scores of scales to categorize individuals as either healthy or depressed. This approach assumes that depression is a single condition and all symptoms are equally good severity indicators.[20] However, evidence to substantiate this assumption is insufficient, as different depressive symptoms may have distinct underlying biological mechanisms, varying impacts on impairment, and diverse risk factors.[20] Therefore, it is essential to investigate the association between internet exclusion and each specific depressive symptom to gain a more comprehensive understanding.

To address these research gaps, we conducted a comprehensive longitudinal, cross-cultural analysis using data from five large comparative cohort studies conducted between 2010 and 2020 across 32 countries, including both LMICs and HICs, spanning three continents: North America, Europe, and Asia. Our primary hypothesis was that internet exclusion would be associated with increased likelihood of depressive symptoms among older adults. Additionally, we explored the association between internet exclusion and specific items of depressive symptoms. Furthermore, we conducted subgroup analyses to identify particular subpopulations that may be more susceptible to the association of internet exclusion with depressive symptoms.

Methods

Study design and data sources

Data were collected from five international ageing cohorts: the Health and Retirement Study (HRS),[21] the English Longitudinal Study of Ageing (ELSA),[22] the Survey of Health, Ageing and Retirement in Europe (SHARE),[23] the China Health and Retirement Longitudinal Study (CHARLS),[24] and the Mexican Health and Ageing Study (MHAS).[25] All five cohort studies provide information on internet exclusion and depressive symptoms among individuals aged 60 and above. In this study, we utilized data spanning from 2010 to 2020. Within this time frame, we excluded the ELSA 2010 survey and SHARE 2010 survey due to the absence of questions pertaining to internet exclusion. The final waves included for each study were as follows: 2010–2020 for HRS, 2012–2019 for ELSA, 2013–2020 for SHARE, 2011–2020 for CHARLS, and 2012–2018 for MHAS.

Subsequently, we excluded participants below the age of 60 and those with missing data regarding internet exclusion, depressive symptoms, and covariates. As a result, our final analytical sample comprised 18,619 participants with 60,291 observations from HRS, 8726 participants with 24,185 observations from ELSA, 76,255 participants with 146,029 observations from SHARE, 13,556 participants with 41,290 observations from CHARLS, and 12,691 participants with 27,729 observations from MHAS (Supplementary Fig. S1). The response rates was 77.0% in HRS, 83.9% in ELSA, 96.6% in SHARE, 87.6% in CHARLS, and 90.5% in MHAS.

Measures

The measurements of exposure (internet exclusion), outcome (depressive symptoms), and covariates (demographics, socio-economic positions, living arrangements, lifestyles, presence of chronic diseases, cognitive impairment, and functional ability) were respectively assessed across all five cohorts at each wave survey.

Internet exclusion

Internet exclusion was determined as a binary variable, categorized as "yes" or "no" based on the following question: "Do you regularly use the Internet (or the World Wide Web) for sending and receiving e-mail or for any other purpose, such as making purchases, searching for information, or making travel reservations?" in HRS, "In the last 7 days, have you used the Internet at least once for e-mailing, searching for information, making purchases, or for any other purpose?" in SHARE, "Have you used the Internet in the past month?" in CHARLS, and "Do you have Internet access at home?" in MHAS. In ELSA, internet exclusion was assessed using the question: "On average, how often do you use the Internet or email?", and participants could choose from the following options: "every day", "at least once a week", "at least once a month", "at least once every 3 months", "less than every 3 months", and "never". The response "no" (in HRS, SHARE, CHARLS, and MHAS) or a frequency of less than once a week (in SHARE) was classified as internet exclusion, while the response "yes" or a frequency of at least once a week was considered as internet inclusion.[11]

Depressive symptoms

Both the Centre for Epidemiologic Studies of Depression scale (CES-D) and Euro-Depression scale (Euro-D) were self-administrated scales used to measure depressive symptoms.[26,27] Depressive symptoms were assessed using the CES-D scale in HRS (CESD-8), ELSA (CESD-8), CHARLS (CESD-10), and MHAS (CESD-9), and the Euro-D scale in SHARE.[26–28] The total scores for these scales ranged from 0 to 8, 0 to 8, 0 to 30, 0 to 12, and 0 to 9, respectively. Depressive symptoms were identified by scores equal to or above predefined cutoff values: 10 for CHARLS, 3 for HRS, 3 for ELSA, 4 for SHARE, and 5 for MHAS.[26,29] Each item on the CES-D and Euro-D scales was dichotomously categorized, with "yes" denoting the presence of pertinent negative emotions and "no" indicating their absence.

Covariates

Demographic factors (age and gender), socio-economic indicators (education level, labor force status, and household wealth level), living arrangements (marital status, residential status, and co-residence with children), lifestyle factors (smoking, drinking, and physical activity), presence of chronic physical diseases, cognitive impairment, and functional ability were selected as covariates based on prior research findings. Additional details regarding the covariates can be found in the Supplementary materials.

Statistical analysis

The idea of this study was conceived in August 2023, and the final data acquisition and analysis were conducted in April 2024. We performed statistical descriptions and analyses for each of the five cohorts. For continuous variables, the means and standard deviations were calculated, while for categorical variables, the numbers and percentages were calculated. Missing data for items were assumed to be missing at random and imputed using the expectation maximization algorithm.[30]

To account for the intercorrelation among repeated measures within each cohort, we utilized Generalized Estimating Equations (GEE) models. With the panel data approach, random-effects logistic regression models, implemented within the GEE framework, were used to examine the associations between internet exclusion and the likelihood of experiencing depressive symptoms by estimating the odds ratio (OR) and its corresponding 95% confidence interval (CI). A minimal sufficient adjustment set (MSAS) was selected as priori potential confounders using a causal directed acyclic graph (DAG) (Supplementary Fig. S2). The MSAS included gender, age, socio-economic positions (education, labour force status, and household wealth level), marital status, co-residence with children, residence status, cognitive impairment, and difficulty in basic activities of daily living (BADL) and instrumental activities of daily living (IADL). Four models were fitted: Model 1 with no covariates adjusted, Model 2 with age and gender adjusted, Model 3 with MSAS adjusted, and Model 4 with all covariates adjusted. Furthermore, we examined the association between internet exclusion and performance on each item of depressive symptoms in all five cohorts, using a consistent MSAS-controlled model. Subgroup analyses were further conducted to evaluate whether these associations varied across different population groups, using the aforementioned GEE regression analyses, adjusted for the MSAS with the stratification variable removed.

Several sensitivity analyses were conducted. Firstly, we repeated the GEE analyses by fitting a logistic regression model solely in the participants who were free of depressive symptoms at baseline and attended more than one follow-up visit. Secondly, to mitigate recall bias, we conducted analyses excluding participants with severe cognitive impairment at baseline to assess the associations between internet exclusion and depressive symptoms. Thirdly, to account for the substantial impact of the COVID-19 pandemic on the mental health of older adults, we conducted a further sensitivity analysis by excluding survey data collected during the COVID-19 pandemic. Finally, in order to provide a more comprehensive understanding of any potential biases inherent in each dataset, we conducted sensitivity analysis based on cross-sectional studies at each wave to thoroughly investigate the association between internet exclusion and depressive symptoms. Statistical analyses were performed using Stata statistical software version 15.0 and R statistical software version 4.0.2. A two-sided P value less than 0.05 was considered statistically significant.

Ethics statement

In this study, de-identified data from five publicly available databases (HRS, ELSA, SHARE, CHARLS, and MHAS) were used. The ethical approval was approved by the original surveys, and no additional ethical approval was required for the present study. The informed consents were obtained from all participants by the original surveys.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

Characteristics between observations included and excluded based on panel data during 2010 and 2020 were shown in Supplementary Table S1. The number of missing data among observations included on panel data analysis was shown in Supplementary Table S2. The characteristics of the first wave surveys in the five cohort studies were shown in Supplementary Table S3. The characteristics of included observations in the five cohort studies were presented in Table 1. The average

Characteristics	HRS	ELSA	SHARE	CHARLS	MHAS
	N (%)	N (%)	N (%)	N (%)	N (%)
Total	60,291	24,185	146,029	41,290	27,729
Age(ys), Mean(SD), Median (Q1–Q3)	71.7 (8.3), 71 (65–78)	71.0 (7.6), 70 (65–76)	71.6 (8.0), 70 (65–77)	68.1 (6.4), 67 (63–72)	70.6 (7.6), 69 (65–76)
60–69	27,080 (44.9)	11,820 (48.9)	67,448 (46.2)	26,622 (64.5)	14,051 (50.7)
70–79	21,630 (35.9)	8576 (35.4)	51,910 (35.6)	12,000 (29.1)	9814 (35.4)
80 and older	11,581 (19.2)	3789 (15.7)	26,671 (18.2)	2668 (6.4)	3864 (13.9)
Gender					
Male	25,347 (42.0)	11,005 (45.5)	64,952 (44.5)	20,592 (49.9)	12,367 (44.6)
Female	34,944 (58.0)	13,180 (54.5)	81,077 (55.5)	20,698 (50.1)	15,362 (55.4)
Education					
Primary school and below	9644 (16.0)	6567 (27.2)	61,873 (42.4)	37,876 (91.7)	24,633 (88.8)
Secondary school	35,601 (59.0)	12,823 (53.0)	53,032 (36.3)	2719 (6.6)	706 (2.6)
College and above	15,046 (25.0)	4795 (19.8)	31,124 (21.3)	695 (1.7)	2390 (8.6)
Marital status					
Married and partnered	37,134 (61.6)	16,924 (70.0)	104,155 (71.3)	32,797 (79.4)	17,687 (63.8)
Unmarried and others	23,157 (38.4)	7261 (30.0)	41,874 (28.7)	8493 (20.6)	10,042 (36.2)
Labour force status					
Not working	43,433 (72.0)	19,320 (79.9)	118,024 (80.8)	19,954 (48.3)	19,604 (70.7)
Working	16,858 (28.0)	4865 (20.1)	28,005 (19.2)	21,336 (51.7)	8125 (29.3)
Household wealth[a]					
Group 1 (most deprived)	14,574 (24.2)	5948 (24.6)	36,824 (25.2)	8175 (25.6)	6914 (24.9)
Group 2	14,151 (23.5)	5551 (23.0)	35,535 (24.3)	7590 (23.8)	6550 (23.6)
Group 3	15,497 (25.7)	6418 (26.5)	36,979 (25.3)	8217 (25.7)	7172 (25.9)
Group 4 (most affluent)	16,069 (26.6)	6268 (25.9)	36,691 (25.2)	7968 (24.9)	7093 (25.6)
Co-residence with children[b]					
No	39,075 (77.4)	20,102 (83.1)	122,935 (84.2)	22,488 (54.5)	7981 (28.8)
Yes	11,415 (22.6)	4083 (16.9)	23,094 (15.8)	18,802 (45.5)	19,748 (71.2)
Residence status[c]					
Urban	43,581 (72.3)	–	98,958 (67.8)	15,683 (38.0)	19,668 (70.9)
Rural	16,710 (27.7)	–	47,071 (32.2)	25,607 (62.0)	8061 (29.1)
Smoking status					
Never	26,566 (44.0)	8753 (36.2)	84,352 (57.8)	22,497 (54.5)	16,905 (61.0)
Former	27,650 (45.9)	13,375 (55.3)	41,638 (28.5)	8480 (20.5)	8036 (29.0)
Current	6075 (10.1)	2057 (8.5)	20,039 (13.7)	10,313 (25.0)	2788 (10.1)
Drinking frequency					
No	27,182 (45.1)	3361 (13.9)	73,690 (50.5)	23,583 (57.1)	21,599 (77.9)
Yes	33,109 (54.9)	20,824 (86.1)	72,339 (49.5)	17,707 (42.9)	6130 (22.1)
Physical activity					
Inactive	19,086 (31.7)	5656 (23.4)	27,591 (18.9)	16,905 (40.9)	–
Moderate	20,260 (33.6)	11,636 (48.1)	55,410 (37.9)	12,695 (30.8)	–
Inactive and moderate	–	–	–	–	18,633 (67.2)
Vigorous	20,945 (34.7)	6893 (28.5)	63,028 (43.2)	11,690 (28.3)	9096 (32.8)
Number of comorbidities					
None	5609 (9.3)	3546 (14.7)	7989 (5.5)	7009 (17.0)	5703 (20.6)
One	12,969 (21.5)	6220 (25.7)	25,433 (17.4)	9802 (23.7)	8791 (31.7)
Two and above	41,713 (69.2)	14,419 (59.6)	112,607 (77.1)	24,479 (59.3)	13,235 (47.7)
Cognitive impairment[d]					
No	39,430 (96.4)	23,491 (97.1)	142,372 (97.5)	38,464 (93.2)	26,109 (94.2)
Yes	1458 (3.6)	694 (2.9)	3657 (2.5)	2826 (6.8)	1620 (5.8)
Difficulty in BADL					
No	50,073 (83.1)	20,033 (82.8)	127,451 (87.3)	32,691 (79.2)	21,826 (78.7)
Yes	10,218 (16.9)	4152 (17.2)	18,578 (12.7)	8599 (20.8)	5903 (21.3)
Diffifficulty in IADL					
No	47,294 (78.4)	19,349 (80.0)	116,672 (79.9)	27,997 (67.8)	23,625 (85.2)

(Table 1 continues on next page)

Characteristics	HRS	ELSA	SHARE	CHARLS	MHAS
	N (%)	N (%)	N (%)	N (%)	N (%)
(Continued from previous page)					
Yes	12,997 (21.6)	4836 (20.0)	29,357 (20.1)	13,293 (32.2)	4104 (14.8)
Internet exclusion					
No	32,544 (54.0)	16,288 (67.4)	66,003 (45.2)	3169 (7.7)	9614 (34.7)
Yes	27,747 (46.0)	7897 (32.6)	80,026 (54.8)	38,121 (92.3)	18,115 (65.3)
Depression					
No	48,566 (80.5)	19,870 (82.2)	129,875 (88.9)	25,710 (62.3)	18,754 (67.6)
Yes	11,725 (19.5)	4315 (17.8)	16,154 (11.1)	15,580 (37.7)	8975 (32.4)

The unit of analysis is at the observation level rather than the individual level. BADL: basic activities of daily living; CHARLS: China Health and Retirement Longitudinal Study; ELSA: English Longitudinal Study of Ageing; HRS: Health and Retirement Study; IADL: instrumental activities of daily living; MHAS: Mexican Health and Ageing Study; SHARE: Survey of Health, Ageing and Retirement in Europe. [a]For CHARLS, the question on household wealth was unavailable in W5 (n = 9340). [b]The question on co-residence with children was unavailable in HRS W15 (n = 9801). [c]For ELSA, the question on residence status was unavailable. [d]For HRS, the question on cognitive impairment was unavailable in both W14 (n = 9602) and W15 (n = 9801).

Table 1: **Descriptive statistics in HRS, ELSA, SHARE, CHARLS and MHAS based on panel data analysis during 2010 and 2020.**

age of participants in HRS, ELSA, SHARE, CHARLS, and MHAS were 71.7, 71.0, 71.6, 68.1, and 70.6 years, respectively. The proportion of males in HRS, ELSA, SHARE, CHARLS, and MHAS were 42.0%, 45.5%, 44.5%, 49.9% and 44.6%, respectively (Table 1). The proportion of internet exclusion among older adults varied widely across countries, ranging from 21.9% in Denmark (SHARE) to 92.3% in China (CHARLS). The pooled proportion of depressive symptoms was 46.0% in HRS, 32.6% in ELSA, 54.8% in SHARE, and 65.3% in MHAS. Additionally, the proportion of depressive symptoms among older adults also displayed variation across countries, with rates ranging from 3.8% in Switzerland (SHARE) to 37.7% in China (CHARLS) (Fig. 1). The overall proportion of depressive symptoms was 19.5% in HRS, 17.8% in ELSA, 11.1% in SHARE, and 32.4% in MHAS (Table 1).

Fig. 2 illustrates the association between internet exclusion and depressive symptoms. In the crude model (Model 1), internet exclusion was found to be significantly associated with depressive symptoms in all cohort studies and countries, except for older adults in Finland

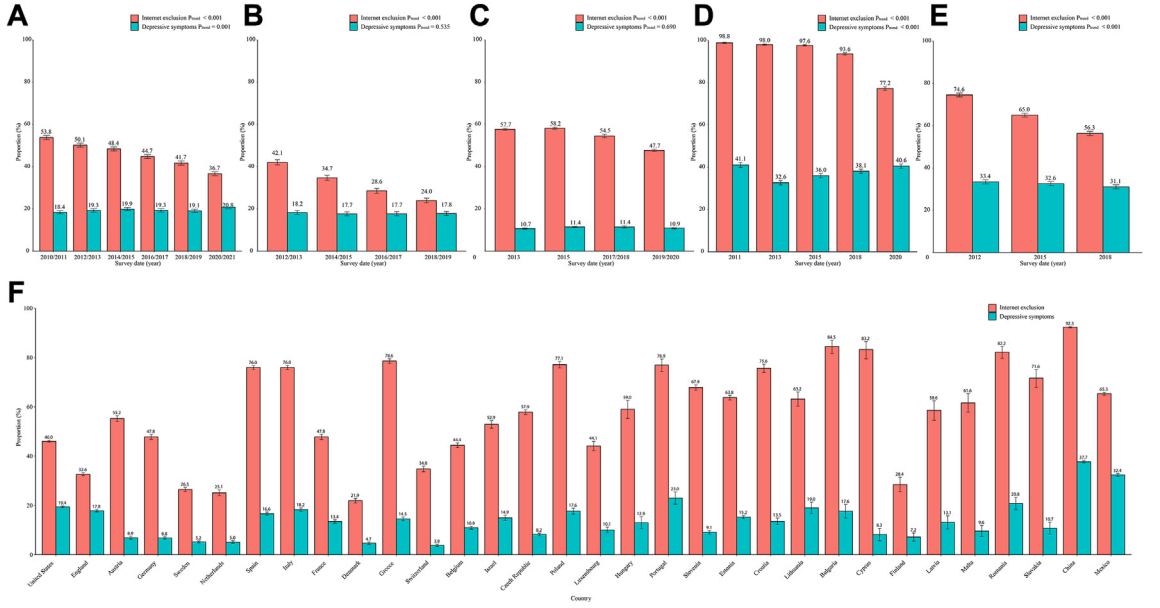

Fig. 1: Proportion of internet exclusion and depressive symptoms. Note: The images A, B, C, D and E illustrate the proportions of internet exclusion and depressive symptoms by survey year in the following studies: HRS (Health and Retirement Study), ELSA (English Longitudinal Study of Ageing), SHARE (Survey of Health, Ageing and Retirement in Europe), CHARLS (China Health and Retirement Longitudinal Study), and MHAS (Mexican Health and Ageing Study), respectively. Additionally, image F presents the proportions of internet exclusion and depressive symptoms categorized by country. Chi-square test for trend was used to compare the trends in internet exclusion and depressive symptoms across different survey waves.

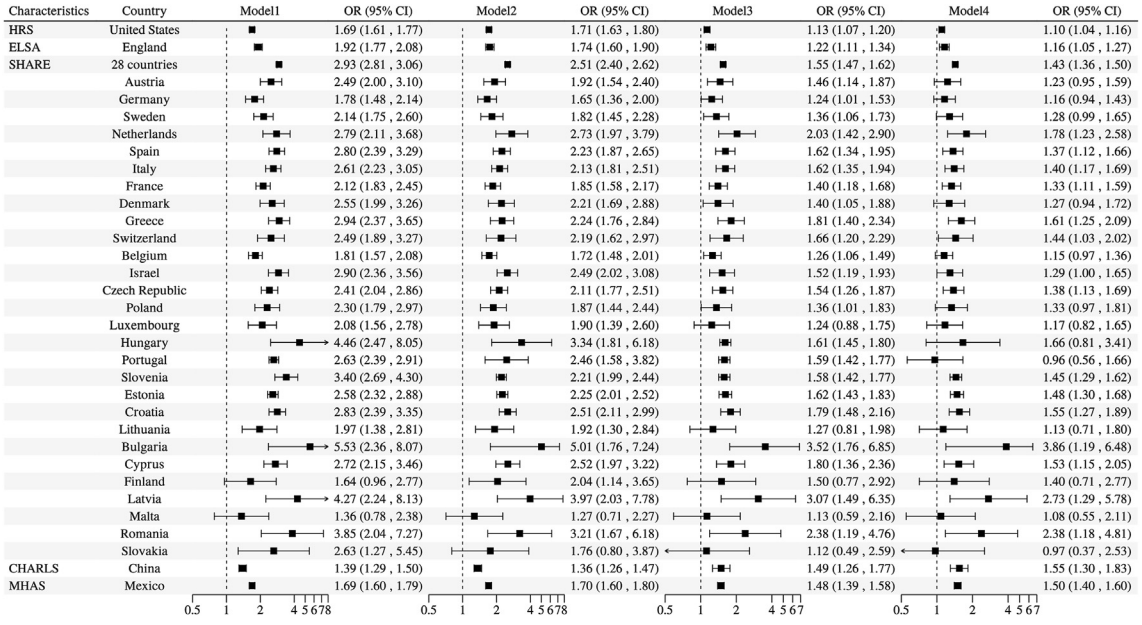

Fig. 2: Association between internet exclusion and depressive symptoms, based on panel data analysis during 2010 and 2020. Note: CHARLS: China Health and Retirement Longitudinal Study; ELSA: English Longitudinal Study of Ageing; HRS: Health and Retirement Study; MHAS: Mexican Health and Ageing Study; OR: odd ratio; SHARE: Survey of Health, Ageing and Retirement in Europe. The 28 countries in SHARE include Austria, Germany, Sweden, Netherlands, Spain, Italy, France, Denmark, Greece, Switzerland, Belgium, Israel, Czech Republic, Poland, Luxembourg, Hungary, Portugal, Slovenia, Estonia, Croatia, Lithuania, Bulgaria, Cyprus, Finland, Latvia, Malta, Romania, and Slovakia. Model 1 was crude model. Model 2 was adjusted for gender and age. Model 3 was adjusted for the minimal sufficient adjustment set (MSAS) identified using a causal directed acyclic graph (DAG) including further adjusted for education, marital status, labour force status, household wealth, co-residence with children, residence status, cognitive impairment, difficulty in basic activities of daily living (BADL) and difficulty in instrumental activities of daily living (IADL) based on Model 2. Model 4 was further adjusted for smoking, drinking, physical activity and number of comorbidities based on Model 3.

and Malta. After adjusting for MSAS (Model 3), these associations remained statistically significant in HRS (OR = 1.13, 95% CI 1.07–1.20), ELSA (OR = 1.22, 95% CI 1.11–1.34), SHARE (OR = 1.55, 95% CI 1.47–1.62), CHARLS (OR = 1.49, 95% CI 1.26–1.77), and MHAS (OR = 1.48, 95% CI 1.39–1.58). Furthermore, these associations remained significant in the fully adjusted model (Model 4) for all five cohort studies.

To assess the heterogeneity of internet exclusion on depressive symptoms, Fig. 3 illustrates the association between internet exclusion and depressive symptoms across various subpopulations. Subgroup analyses revealed that these associations remained significant in adults younger than 80 years, those currently not working, individuals in the most deprived household wealth group, individuals with primary school education or below, and those without any difficulty in performing BADL and IADL.

Internet exclusion were associated with all dimensions of depression in SHARE, MHAS, and ELSA (except for sleep and felt sad) cohorts (Tables 2–3). Two symptoms of CES-D, namely "everything is an effort" and "feeling lonely", were significantly associated with internet exclusion in HRS, ELSA, and MHAS. The item "could not get going" showed significant associations with internet exclusion in HRS, ELSA, and CHARLS.

In the follow-up cohort study, the risk of depressive symptoms was higher in individuals who were excluded from the internet compared to their counterparts in SHARE and MHAS when we excluded older adults with depressive symptoms at baseline (Supplementary Table S4). Additionally, internet exclusion was significantly associated with the item "everything is an effort" in HRS, ELSA, CHARLS, and MHAS (Supplementary Table S5).

After excluding participants with severe cognitive impairment at baseline, internet exclusion were still significantly associated with depressive symptoms in all the five cohort studies (Supplementary Table S4). Two symptoms of the CES-D scale, namely "everything is an effort"" and "did not feel happy", were significantly associated with internet exclusion in HRS, ELSA, CHARLS, and MHAS (Supplementary Table S6). Additionally, all specific depressive symptoms of the Euro-D scale were associated with internet exclusion in SHARE when participants with severe cognitive impairment at baseline were excluded (Supplementary Table S7).

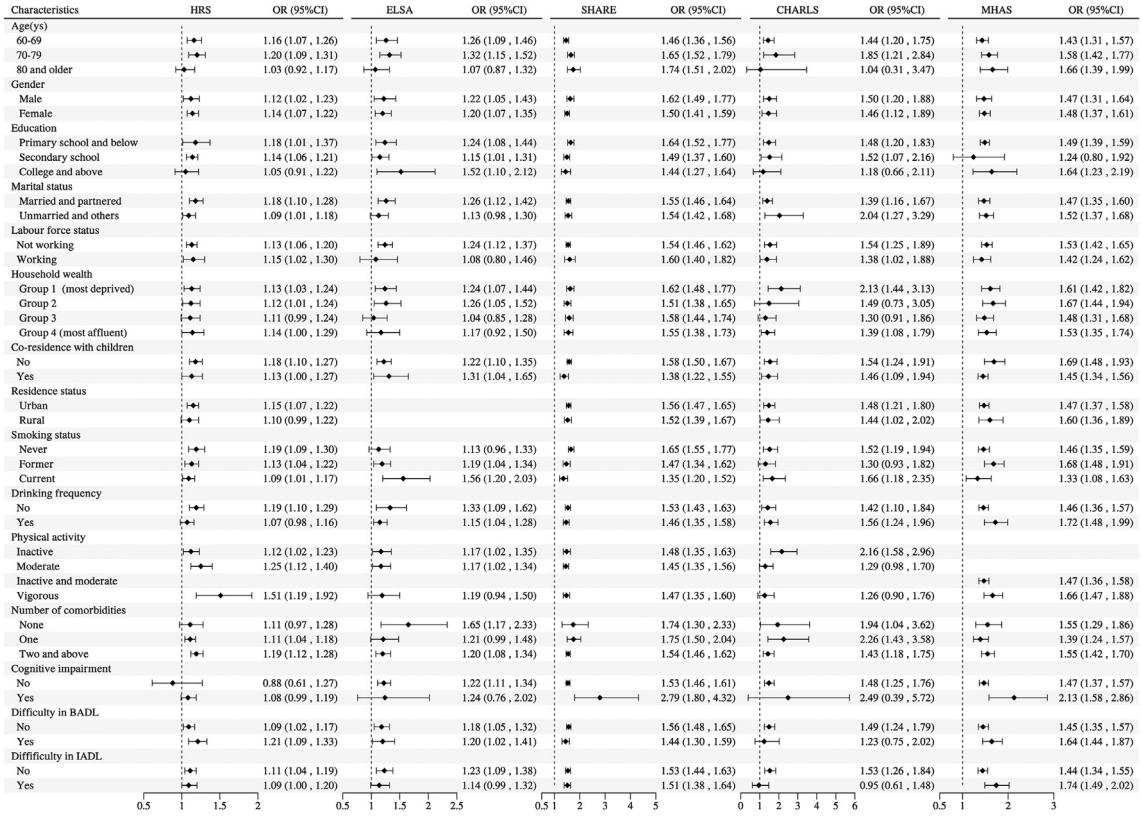

Fig. 3: Association between internet exclusion and depressive symptoms stratified by different factors, based on panel data analysis during 2010 and 2020. Note: BADL: basic activities of daily living; CHARLS: China Health and Retirement Longitudinal Study; ELSA: English Longitudinal Study of Ageing; HRS: Health and Retirement Study; IADL: instrumental activities of daily living; MHAS: Mexican Health and Ageing Study; OR: odd ratio; SHARE: Survey of Health, Ageing and Retirement in Europe. Model was adjusted for the minimal sufficient adjustment set (MSAS) identified using a causal directed acyclic graph (DAG) including gender, age, education, marital status, labour force status, household wealth, co-residence with children, residence status, cognitive impairment, difficulty in BADL and difficulty in IADL.

When we further excluded the survey data collected during the COVID-19 pandemic, the association between internet exclusion and depressive symptoms remained significant in HRS, SHARE, and CHARLS (Supplementary Table S8). The results of the stratified analysis were consistent with the analysis conducted using survey data collected during the COVID-19 pandemic (Supplementary Table S9). Specifically, internet exclusion was still significantly associated with the item "everything is an effort" in HRS and CHARLS, and with all dimensions of depression in SHARE (Supplementary Tables S10 and S11). The results of the cross-sectional studies showed that internet exclusion was significantly associated with depressive symptoms in all survey waves of SHARE and MHAS, as well as in the majority of survey waves in HRS, ELSA, and CHARLS (Supplementary Table S12).

Discussion

To the best of our knowledge, this study is the first panel data analysis to examine the association between internet exclusion and depressive symptoms among older adults. The results of our study revealed a significant association between internet exclusion and a higher likelihood of experiencing depression, as well as most specific depressive symptoms, in both HICs (HRS, ELSA, and SHARE) and LMICs (CHARLS, and MHAS). These associations were particularly pronounced among adults younger than 80 years, those currently not working, individuals in the most economically deprived household wealth group, individuals with primary school education or below, and those without any difficulty in performing BADL and IADL.

As ICTs become more prevalent and society undergoes ongoing internet transformation, internet exclusion among the older adults has garnered increasing attention. The prevalence of internet exclusion varies between HICs and LMICs. Representative data across 17 European countries highlighted that 51% of individuals aged over 50 did not use the internet.[31] In China, 61.4% of individuals over the age of 60 years did not use the internet in 2018.[32] Previous studies have indicated that older individuals who do not use or have

limited use of internet technologies are at a higher risk of experiencing depressive symptoms, loneliness, and a stronger sense of exclusion.[10,33] In this study, we also observed a significant association between internet exclusion and depressive symptoms among older adults across all five cohorts, with several potential explanations. Firstly, internet exclusion restricts older adults' social connections and communication channels, increasing the risk of loneliness and social isolation,[34] and leading to various psychiatric disorders such as depression.[35] Throughout the COVID-19 pandemic, necessary social distancing measures and widespread lockdowns have left internet excluded older adults without access to vital support and information from their families, friends, and communities. This unfortunate loss of social resources exacerbates the risk of experiencing loneliness, isolation, and depression among this vulnerable demographic.[36] Secondly, ICTs are currently transforming the delivery of internet healthcare services, such as e-Health, m-Health, telemedicine.[37] Internet excluded older adults may lack appropriate internet channels to access and utilize these internet health care services, especially during the COVID-19 pandemic, and this deficiency may engender feelings of helplessness and insecurity. Thirdly, internet exclusion can have a detrimental effect on the cognitive functioning and psychological stimulation of older adults.[38] ICTs offer a wide range of cognitive stimulation and challenges, such as learning new skills and engaging in intellectually stimulating activities. When older adults are unable to access these stimulations due to internet exclusion, it can significantly impact their cognitive functioning and potentially lead to mental health issues.[39]

Depression is a complex psychological state characterized by symptoms such as a depressed mood, diminished interest or pleasure, changes in weight or appetite, insomnia, psychomotor agitation or retardation, fatigue or loss of energy, feelings of guilt or worthlessness, difficulty concentrating, and recurrent thoughts of death or suicide.[20] Depression symptoms are not equivalent, and individuals with the same total scores on a depression scale may exhibit drastically different levels of severity in their clinical conditions.[20] Evaluating individual items of depression allows us to obtain a comprehensive and detailed understanding of the specific dimensions in which depressive symptoms are impacted by internet exclusion, which is crucial for personalized interventions of depressive symptoms. This study is the first to investigate the association between internet exclusion and various dimensions of depression. Our results indicated that internet exclusion were associated with most specific depressive symptoms. For instance, this study found a significant association between internet exclusion and the item "everything an effort" on the CES-D scale

CES-D items[a]	HRS			ELSA			CHARLS			MHAS		
	N (%)[b]	OR (95% CI)[c]	P	N (%)[b]	OR (95% CI)[c]	P	N (%)[b]	OR (95% CI)[c]	P	N (%)[b]	OR (95% CI)[c]	P
Felt depressed	6884 (11.4)	1.29 (1.20, 1.38)	<0.001	2542 (10.5)	1.41 (1.26, 1.58)	<0.001	19,147 (46.4)	1.09 (0.94, 1.25)	0.251	9601 (34.6)	1.34 (1.25, 1.42)	<0.001
Everything an effort	13,319 (22.1)	1.42 (1.34, 1.49)	<0.001	4223 (17.45)	1.36 (1.24, 1.49)	<0.001	19,551 (47.4)	1.34 (1.15, 1.56)	<0.001	10,030 (36.2)	1.47 (1.38, 1.57)	<0.001
Sleep was restless	17,226 (28.6)	1.02 (0.98, 1.07)	0.321	8987 (37.2)	0.95 (0.88, 1.02)	0.153	21,237 (51.4)	1.00 (0.87, 1.15)	0.999	11,883 (42.9)	1.22 (1.15, 1.30)	<0.001
Did not felt happy	7548 (12.5)	1.02 (0.96, 1.09)	0.480	1990 (8.2)	1.22 (1.08, 1.39)	<0.001	23,023 (55.8)	1.42 (1.23, 1.63)	<0.001	5626 (20.3)	1.28 (1.19, 1.38)	<0.001
Felt lonely	9533 (15.8)	1.11 (1.04, 1.18)	<0.001	2427 (10.0)	1.31 (1.16, 1.46)	<0.001	12,148 (29.4)	1.03 (0.87, 1.21)	0.730	8660 (31.2)	1.51 (1.41, 1.61)	<0.001
Felt tired	–	–	–	–	–	–	–	–	–	11,447 (41.3)	0.81 (0.76, 0.86)	<0.001
Did not had a lot of energy	–	–	–	–	–	–	–	–	–	12,379 (44.6)	0.87 (0.82, 0.92)	<0.001
Did not enjoyed life	4867 (8.1)	0.92 (0.85, 1.00)	0.052	1829 (7.6)	1.22 (1.07, 1.39)	<0.001	–	–	–	6455 (23.3)	1.43 (1.33, 1.53)	<0.001
Felt sad	10,388 (17.2)	1.03 (0.97, 1.09)	0.353	4037 (16.7)	1.08 (0.98, 1.18)	0.131	–	–	–	11,072 (40.0)	1.22 (1.15, 1.30)	<0.001
Could not get going	11,488 (19.1)	1.17 (1.11, 1.24)	<0.001	4340 (18.0)	1.24 (1.13, 1.36)	<0.001	8975 (21.7)	1.49 (1.17, 1.90)	<0.001	–	–	–
Bothered by little things	–	–	–	–	–	–	18,640 (45.1)	0.97 (0.85, 1.12)	0.723	–	–	–
Had trouble keeping mind on what is doing	–	–	–	–	–	–	18,368 (44.5)	1.09 (0.95, 1.25)	0.231	–	–	–
Did not feel hopeful about the future/Pessimism	–	–	–	–	–	–	25,943 (62.8)	1.31 (1.14, 1.50)	<0.001	–	–	–
Feel fearful	–	–	–	–	–	–	7868 (19.1)	1.07 (0.87, 1.32)	0.512	–	–	–

CHARLS: China Health and Retirement Longitudinal Study; ELSA: English Longitudinal Study of Ageing; HRS: Health and Retirement Study; MHAS: Mexican Health and Ageing Study; OR: odd ratio. [a]Measured by the Center for Epidemiologic Studies Depression Scale (CES-D). [b]The proportion of observations with a "yes" response for a specific depression item in the panel data set. [c]Model was adjusted for the minimal sufficient adjustment set (MSAS) identified using a causal directed acyclic graph (DAG) including gender, age, education, marital status, labour force status, household wealth, co-residence with children, residence status, cognitive impairment, difficulty in BADL (basic activities of daily living) and difficulty in IADL (instrumental activities of daily living).

***Table 2:* Association between internet exclusion and specific depressive symptoms of CES-D scale based on panel data analysis during 2010 and 2020.**

Euro-D items[a]	SHARE		
	N (%)[b]	OR (95% CI)[c]	P
Depression	57,198 (39.2)	1.05 (1.02, 1.08)	<0.001
Pessimism	26,569 (18.2)	1.66 (1.60, 1.72)	<0.001
Suicidality	10,161 (7.0)	1.31 (1.23, 1.39)	<0.001
Guilt	10,743 (7.4)	0.89 (0.85, 0.94)	<0.001
Trouble with sleep	51,963 (35.6)	1.04 (1.02, 1.08)	<0.001
Less interest	14,820 (10.2)	1.49 (1.42, 1.56)	<0.001
Irritability	38,297 (26.2)	1.08 (1.05, 1.12)	<0.001
Diminution in the desire for food	14,023 (9.6)	1.31 (1.25, 1.38)	<0.001
Fatigue	53,718 (36.8)	1.13 (1.10, 1.16)	<0.001
Difficulty in concentration on entertainment or reading	26,542 (18.2)	1.39 (1.34, 1.45)	<0.001
Tearfulness	33,812 (23.2)	1.05 (1.02, 1.09)	0.01
Almost nothing enjoyed	19,334 (13.2)	1.58 (1.52, 1.65)	<0.001

OR: odd ratio; SHARE: Survey of Health, Ageing and Retirement in Europe. [a]Measured by the Euro-Depression Scale (Euro-D). [b]The proportion of observations with a "yes" response for a specific depression item in the panel data set. [c]Model was adjusted for the minimal sufficient adjustment set (MSAS) identified using a causal directed acyclic graph (DAG) including gender, age, education, marital status, labour force status, household wealth, co-residence with children, residence status, cognitive impairment, difficulty in basic activities of daily living (BADL) and difficulty in instrumental activities of daily living (IADL).

Table 3: **Association between internet exclusion and specific depressive symptoms of Euro-D scale based on panel data analysis during 2012 and 2020.**

across the HRS, MHAS, CHARLS, and ELSA databases. This indicates that individuals who experience internet exclusion are more likely to perceive even simple tasks as requiring substantial effort due to their depressive symptoms. These results emphasize the impact of internet exclusion on the motivation and energy levels of individuals with depressive symptoms.

The association between internet exclusion and depressive symptoms remained significant in specific demographic categories: adults younger than 80 years, those currently not working, individuals in the most economically deprived household wealth group, individuals with primary school education or below, and those without any difficulty in performing BADL and IADL. The findings hold significant implications for implementing targeted internet interventions for specific high-risk populations with depressive symptoms. For instance, older adults with lower levels of education and cultural literacy may lack knowledge and skills in internet technology, leading to a sense of discomfort and exclusion in the internet society, thereby increasing the risk of depression. Older adults with poorer economic conditions may reside in areas with inadequate internet infrastructure or be unable to afford the cost of purchasing internet devices and internet connectivity, and this limitation restricts their ability to connect with the outside world and access information, consequently amplifying feelings of isolation and the likelihood of experiencing depression. Furthermore, the lack of employment may lead to the loss of roles and identity among older adults, and internet exclusion may limit their social presence and recreational activities decreasing their opportunities to engage with others, and thereby have less leisure options hence experiencing a higher risk of depressive symptoms. Consequently, our findings underscore the importance of providing internet technology training and establishing supportive and inclusive environments to facilitate the reintegration of unemployed older adults into society and reduce their susceptibility to depressive symptoms.

Our findings have several implications and recommendations. Firstly, special attention should be given to the older adults with depressive symptoms. Improving their mental health requires a comprehensive approach that includes addressing social support, utilizing antidepressants, implementing psychotherapy, and incorporating exercise therapy.[6,40] Secondly, internet inclusion may serve as an intervention target for reducing depressive symptoms among older adults. It is crucial to promote internet inclusion by providing targeted internet skills training, establishing community networks that support older adults' internet participation, and creating a user-friendly internet environment.[41] Ensuring that individuals can fully engage in internet social interactions can facilitate social engagement, reduce social isolation, and promote mental health among older adults.

The strengths of this study included the utilization of a cross-cultural, nationally representative longitudinal survey, a large sample size, the inclusion of specific depression items, the utilization of GEE models to account for correlations among multiple waves of longitudinal data, and the implementation of various sensitivity analyses. However, several limitations should also be mentioned. Firstly, we used the CES-D and Euro-D scales to screen for depressive symptoms instead of the gold standard diagnostic instrument, the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition.[42] Secondly, measurement comparability is an essential prerequisite for robust comparisons across countries.[43] However, five different measures were used to assess depressive symptoms across the five cohorts. While SHARE uses the Euro-D scale of depressive symptoms, HRS, ELSA, CHARLS, and MHAS rely on short version of the CES-D scale. Although previous study had indicated the high correlation and moderate and agreement between CES-D and Euro-D,[43] it also should noted that there are differences in the way individuals report depressive symptoms when using the Euro-D and CES-D scales. Future research is expected to use consistent depression assessment scales to further explore the association between internet exclusion and depression across different countries. Thirdly, our investigation solely focused on the presence of internet exclusion in older adults and did not explore other dimensions of internet use, such as terminal device, frequency, and purpose. Internet exclusion also encompasses factors such as the absence of internet devices, inadequate internet skills, and a lack of

knowledge and confidence regarding internet resources and services. Future research should delve into a more detailed analysis of the association between different dimensions of internet exclusion and depressive symptoms. Fourthly, there were unmeasured covariates in this study, such as family support, cultural beliefs, and internet literacy, which may have impacts on the association between internet exclusion and depressive symptoms. Fifthly, frailty might be a mediating factor in the correlation between internet exclusion and depressive symptoms.[44] However, the variable of frailty was not included in our study. Sixth, the potential explanations for the association between internet exclusion and depressive symptoms, including factors such as feelings of loneliness, social isolation, and barriers to accessing and utilizing internet healthcare services, are derived from a comprehensive literature review. To further understand the possible explanations for the relationship between internet exclusion and depressive symptoms, future research should incorporate these factors and conduct empirical analyses. Seventh, this study is unable to compare the effect sizes of the association between internet exclusion and depressive symptoms across different cohorts and countries. Lastly, it is important to acknowledge that our study only identified a potential association between internet exclusion and depressive symptoms. Causal relationships cannot be established based solely on our findings.

In conclusion, this study identified a significant association between internet exclusion and an increased likelihood of depressive symptoms among older adults in five cohort studies (HRS, ELSA, SHARE, CHARLS, and MHAS). To mitigate the risk of depressive symptoms, it is crucial to implement effective interventions that aim to enhance the participation of older adults in the digital society, specifically targeting internet exclusion.

Contributors

Rui Yan and Jie Zhao conceptualized study design. Rui Yan and Jie Zhao conducted investigation and methodology. Rui Yan implemented data curation, statistical analysis, and drafted the manuscript. Fangfang Cui and Xiaoran Duan accessed and verified the analysis. Xinwei Liu, Ruyue Xue, Lifeng Li, Xiaoran Duan, Xianying He, and Fangfang Cui reviewed and edited the manuscript. Rui Yan, Xinwei Liu, and Jie Zhao contributed to the funding acquisition and supervised the research. All authors had full access to the data and accept the responsibility to submit the manuscript.

Data sharing statement

The original survey datasets from HRS, ELSA, SHARE, CHARLS, and MHAS are freely available to all bona fide researchers.

Declaration of interests

The authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.eclinm.2024.102767.

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