Impacts of the hearing aid intervention on healthcare utilization and costs among middle-aged and older adults: results from a randomized controlled trial in rural China

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Summary

Background Hearing impairment has become a major global health issue. To reduce the burden of hearing impairment, we explored impacts of the hearing aid intervention on healthcare utilization and costs.

Methods In this randomized controlled trial, participants aged 45+ were allocated with a ratio of 1:1.5 (intervention: control). Neither the investigators nor the assessors were blinded to the allocation status. Those in the intervention group were fitted with hearing aids, and those in the control group received no care. We applied the difference-in-difference (DID) approach to examine the impacts on healthcare utilization and costs. Given that social network and age can be significant variables affecting effectiveness of the intervention, subgroup analyses by social network and age were used to explore the heterogeneity.

Findings 395 subjects were successfully recruited and randomized. 10 subjects did not meet the inclusion criteria and therefore, 385 eligible subjects (150 in the treatment group and 235 in the control group) were analyzed. The intervention significantly reduced their total healthcare costs (average treatment effect (ATE) = −1.26, 95% CI = −2.39, −0.14, p = 0.028) and total out-of-pocket (OOP) healthcare costs (ATE = −1.29, 95% CI = −2.37, −0.20, p = 0.021) in the 20-month follow-up. To be exact, it reduced self-medication costs (ATE = −0.82, 95% CI = −1.49, −0.15, p = 0.016) and OOP self-medication costs (ATE = −0.84, 95% CI = −1.46, −0.21, p = 0.009). Subgroup analysis showed that the impacts on self-medication costs and OOP self-medication costs varied by social network (ATE for self-medication costs = −0.26, 95% CI = −0.50, −0.01, p = 0.041; ATE for OOP self-medication costs = −0.27, 95% CI = −0.52, −0.01, p = 0.038). The impacts also varied by age groups (ATE for self-medication costs = −0.22, 95% CI = −0.40, −0.04, p = 0.019; ATE for OOP self-medication costs = −0.17, 95% CI = −0.29, −0.04, p = 0.010). There were no adverse events or side effects during the trial.

Interpretation Hearing aid use significantly lowered self-medication costs and total healthcare costs, but had no impacts on inpatient or outpatient services utilization or costs. The impacts were manifested among people with active social network or younger age. It can be speculated that the intervention may be adapted to other similar settings in developing countries to reduce healthcare costs.

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Trial registration Chinese Clinical Trial Registry: ChiCTR1900024739.

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Research in context

Evidence before this study

We used the key words "hearing", "hearing aids", "healthcare utilization", and "healthcare cost" to search PubMed, Science Direct, Web of Science, the China National Knowledge Internet, Wanfang Data, and official websites of the World Health Organization (WHO) for articles and reports on hearing aids and healthcare outcomes published up to April 30, 2022, with language restricted to English and Chinese. Previous studies about hearing aids and healthcare utilization/costs are quite limited and mostly from high income countries. Most studies revealed that hearing aid use was associated with healthcare utilization and costs.

Added value of this study

This paper brought new evidence to literature by conducting a randomized controlled trial in rural China to provide free hearing aids for the middle-aged and older adults with hearing loss. Using the difference-in-difference approach, we found that hearing aids use significantly lowered self-medication costs and total healthcare costs among participants aged 45+, but had no impacts on inpatient or outpatient services utilization or costs. Subgroup analysis showed that the impacts were manifested among people with active social network or younger age.

Implications of all the available evidence

To our knowledge, no literature so far has explored the causal effects of hearing aid use on healthcare utilization and costs. Due to the high burden of hearing impairment, it is imperative to explore whether hearing aid use can help reduce healthcare utilization and costs. Our study will help provide the latest evidence for promoting hearing rehabilitation and achieving healthy aging in developing countries.

Introduction

Hearing impairment has become a major global health issue and its prevalence is increasing rapidly.[1] The Global Burden of Disease (GBD) study in the most recent 2019 update indicated that age-related hearing loss was the third highest ranked contributor to years lived with disability (YLDs) behind low back pain and migraine.[2] Among individuals older than 70 years of age, it was the leading cause of global YLDs.[2] In addition, the risk of hearing impairment increases rapidly with age, and the prevalence of hearing impairment in older adults is significantly higher than that in other groups.[3] According to the World Health Organization (WHO) estimates, the current rate of hearing disability (defined as the pure-tone average ≥ 41 dB) was 7% in the age group of 15–65, but for people over 65 it rose to about one-third.[4]

Hearing impairment can be associated with a range of adverse conditions. Hearing impairment itself is related with worse mental health, decreased physical functioning,[5] increased risks of dementia,[6] social isolation,[7] falls,[8] and more frequent inpatient services.[9–11] It can also lead to poor communication in the use of healthcare services,[12] which can further affect their satisfaction,[13,14] treatment adherence,[15] healthcare delivery and utilization,[16] health education,[17] and healthcare costs.[18] WHO estimates that the global cost of unaddressed hearing impairment is $980 billion a year, including costs from healthcare sectors (excluding costs of hearing devices), costs of educational support, costs of productivity loss, and societal costs.[19] The need to address hearing impairment will continue to grow with the aging population.[9]

Hearing aids, as a most common way of hearing rehabilitation, has been shown to reduce hearing impairment and related communication disorders.[20] However, the uptake of hearing aids in both developed and developing countries is relatively low.[21] In the United States, only 14% of hearing-impaired adults aged 50 and older used hearing aids.[22] In terms of developing countries, the prevalence of hearing impairment in the older adults over 60 years old in India was 63.1%, but only 1.47% used hearing aids.[23] A study in Jilin, Guangdong, Shaanxi and Gansu provinces of China found that only 6.5% of the older adults aged 65 years old and above with hearing impairment had hearing aids.[24] In addition, public or private health insurance generally does not cover the costs of hearing tests or hearing aids,[22] which incurs significant out-of-pocket (OOP) costs for those seeking hearing medical services.[25]

Previous studies on hearing aids and healthcare utilization are limited and mainly focus on the context of high-income countries. A study of 1336 Americans over the age of 65 revealed that hearing aid use was associated with changes in healthcare utilization and

increased healthcare costs. To be exact, compared with people with hearing impairment who did not wear hearing aids, those using hearing aids were 2% less likely to be hospitalized or visit the emergency department (20% vs 22%), and for individuals who used healthcare services at least once, the number of days in hospital decreased by 0.46.[26] However, hearing aid use increased the number of outpatient visits by 1.4 (9%). It also increased total medical expenditures by $1125 and out-of-pocket costs by $325.[26] In addition, a number of studies have estimated excess non-hearing healthcare costs in untreated populations,[27] including studies on older adults from the USA,[28–30] adults aged 18–65 from the Netherlands,[31] as well as UK studies on children[32] and teenagers with hearing loss.[33] These results may reflect differences in patterns of healthcare use and disease burden,[26] but their healthcare contexts are very different from those in China so the external validity and relevance are limited.

To our knowledge, no literature so far has explored the causal effects of hearing aids on healthcare utilization and costs. Because of the high costs of hearing impairment, it is imperative to explore whether hearing aid use can help reduce healthcare utilization and costs. We carried out a randomized controlled trial (RCT) among middle-aged and older people aged 45+ with moderate or above hearing impairment in rural eastern China. Given that social network could be an important factor influencing effectiveness of the intervention in healthcare settings,[34] we explored the heterogeneity among individuals with active or restricted social networks. Also, we explored the heterogeneity among individuals aged 45–64 and 65+, as the risk of hearing impairment increased rapidly with age,[35] and effects of hearing impairment were stronger among middle-aged (45–64 years) than older (65+ years) people.[36] The results of this study are expected to provide policy implications for healthcare payers and policy makers when deciding on hearing aid coverage for people with hearing impairment.

Methods

Study design and participants

We conducted a RCT of hearing aid fitting in Yishui and Fei Counties from Linyi City, Shandong Province. Shandong Province has both mountainous areas and plains, as well as coastal and inland areas, which can be representative of China in geography. In addition, Shandong has the second largest population in China, thus providing sufficient sample for the study. Linyi City and further Yishui and Fei Counties were selected randomly by stratified sampling. The trial began in July 2019 and the follow-up was conducted 20 months later. The inclusion criteria of subjects were: (1) people aged 45 and over (45 is the beginning for middle age[37]); (2) clinical diagnosis of moderate or above hearing impairment; (3) currently no hearing aids; (4) living in the study site. The exclusion criteria were: (1) having cognitive, mental, language or movement disability assessed by clinical evaluation and judgments; (2) ever used hearing aids in the past year; (3) unwilling to wear hearing aids every day; (4) medical contraindication of hearing aid use (e.g. otorrhea); (5) incurable conductive hearing impairment in both ears, and the air bone gap between two or more adjacent frequencies was > 15dB.

We focused on impacts of the hearing aid intervention on healthcare utilization and costs among two arms. To detect a difference of 0.09 and a power of 95% in the main outcome of total healthcare costs between study arms, we performed a z-test and would need 400 participants (assuming a drop-out rate of 20%) (Supplementary Material 1).[38] Subjects were randomly selected from a list provided by the Hearing Center of Linyi Disabled Persons' Federation, which recorded all the hearing-disabled people in Linyi City. No blocking was used in the randomization sequence, so the randomization strategy was completely random allocation. As subjects were scattered in different villages, we made the telephone call to the subjects or their close relatives to recruit the target sample. 395 subjects were successfully recruited with a recruitment rate of 87.5%. The number of hearing aids was fixed at the start of the trial, so the allocation ratio was fixed after the initial screening. A researcher not involved in data collection or analysis used a random sequence generator to allocate participants with an allocation ratio of 1: 1.5. (intervention: control) for cost reasons and the possibly higher rate of loss to follow-up for those in the control group, since they did not receive any care.[39,40] Neither the investigators nor the assessors were blinded to the allocation status due to the nature of our trial.

At baseline, all subjects were first tested with pure-tone audiometry. 10 subjects did not meet the inclusion criteria of moderate or above hearing impairment (greater than 40 dB averaged over pure-tone threshold of 0.5, 1.0, 2.0 and 4.0 kHz in the better hearing ear[41]). Therefore, only 385 eligible subjects (150 in the treatment group and 235 in the control group) were finally included and participated in the baseline survey. Their basic information, including health status, health behaviors, social activities, social support, healthcare utilization, etc., were collected. Then, in a separate room, doctors fitted free hearing aids for those in the intervention group. Those in the control arm were told about their hearing loss but were not given any other care. 12 months after the baseline, the intervention group received free hearing aid maintenance, which increased their compliance in wearing hearing aids. In addition, we applied a standardized tool, the International Outcome Inventory for Hearing Aids (IOI-HA), to assess their perceived benefit with hearing aid use (Supplementary Table 1). 67.14% of them used hearing aids for

more than one hour a day; 44.76% used hearing aids for more than four hours a day; 24.48% used hearing aids for more than eight hours a day. 93.27% thought that their hearing aids helped moderately or above when they most wanted to hear better.

A follow-up survey was conducted 20 months after the baseline. Apart from tracking participants' basic information, the study also focused on their hearing aid use and changes in health status and health service utilization. The results of 350 subjects (135 in the intervention group and 215 in the control group) were collected in the follow-up study. 60 participants in the control arm have reported taking up hearing aids in the past year, of which 22 participants have reported using hearing aids more than 1 hour a day in the past two weeks. Each subject was identified according to the unique code assigned, and personal identification information such as the names would not be used in the study. Trial flow diagram for the enrollment and retention of sample is shown in Figure 1. More details of our trial design, intervention, and outcomes can be seen in our trial protocol.[42]

Outcomes: healthcare utilization and costs

We collected information about healthcare utilization and costs via questionnaires at both baseline and follow-up. Healthcare utilization presents as the number of outpatient and inpatient visits. Healthcare costs include outpatient costs, inpatient costs, self-medication costs, as well as their respective OOP costs, but exclusive of hearing aid costs. Respondents recalled outpatient care and self-medication in the past two weeks, and inpatient care in the past year. For a better understanding, all outcome variables were uniformly converted to one-year time units.

(1) Number of outpatient visits: The number of outpatient services or door-to-door services in the past two weeks.
(2) Number of inpatient visits: The number of inpatient services in the past year.
(3) Total healthcare costs: Total healthcare costs and OOP healthcare costs are obtained by adding up the respondents' self-medication, outpatient and inpatient costs, as well as their respective OOP costs in the past year.
(4) Outpatient costs: Total outpatient costs and OOP outpatient costs in the past two weeks.
(5) Inpatient costs: Total inpatient costs and OOP inpatient costs in the past year.
(6) Self-medication costs: Total self-medication costs and OOP self-medication costs in the past two weeks include buying western medicine, treating with traditional Chinese herbal medicine or traditional methods, taking vitamins/supplements/health care products, using healthcare equipment, etc., and exclude taking medicine by prescription. Insured employees can directly use the health insurance funds in their personal health insurance accounts to reimburse the medical expenses in designated retail pharmacies when buying medicines, thereby their self-medication costs and OOP self-medication costs can be different.

Social network

The Lubben Social Network Scale (LSNS) was used to evaluate one's social network (Supplementary Table 2).[43] The scale consists of 10 questions, including two dimensions of family network and friend network. It asks the number and frequency of social contacts and the perceived social support from friends and family members. Each question is 0–5 points, and the total score is 0–50 points. A score < 20 indicates that individuals are isolated and their social network is greatly restricted. A score ≥ 20 represents active social network.[44]

Covariates

The following variables can help to characterize the sample, thus they were selected and used in the analyses: age (continuous), sex (male or female), household registration (rural or urban), levels of education (illiterate, primary, or secondary and above), marital status (married/cohabited or single/widowed), types of work (non-agricultural, agriculture or unemployed), life sources (only rely on themselves or have support from others), health insurance (yes or no), severity of hearing impairment (moderate, severe or profound), chronic diseases (yes or no), smoking status (current smoking, ever smoking, or never smoking), and drinking status (current drinking, ever drinking, or never drinking).

Statistical analysis

Our study is a secondary analysis with outcomes being healthcare utilization and costs (The main outcome in the primary analysis is quality of life). The difference-in-difference (DID) method was used to analyze effects of the hearing aid intervention and to control residual error, leading to more precise estimates of the treatment effect. This approach compares between-period changes in cohorts that receive the intervention with changes in similar cohorts that do not, over a similar time frame.[45] Specifically, we estimated the difference between the intervention minus the control at 20 months and the intervention minus the control at baseline.

In following a DID method, we estimated the impacts of the intervention using negative binomial regression models[46] and tobit models[47] for analyzing outcome variables of healthcare utilization and costs, respectively. Both methods are suitable for analyzing

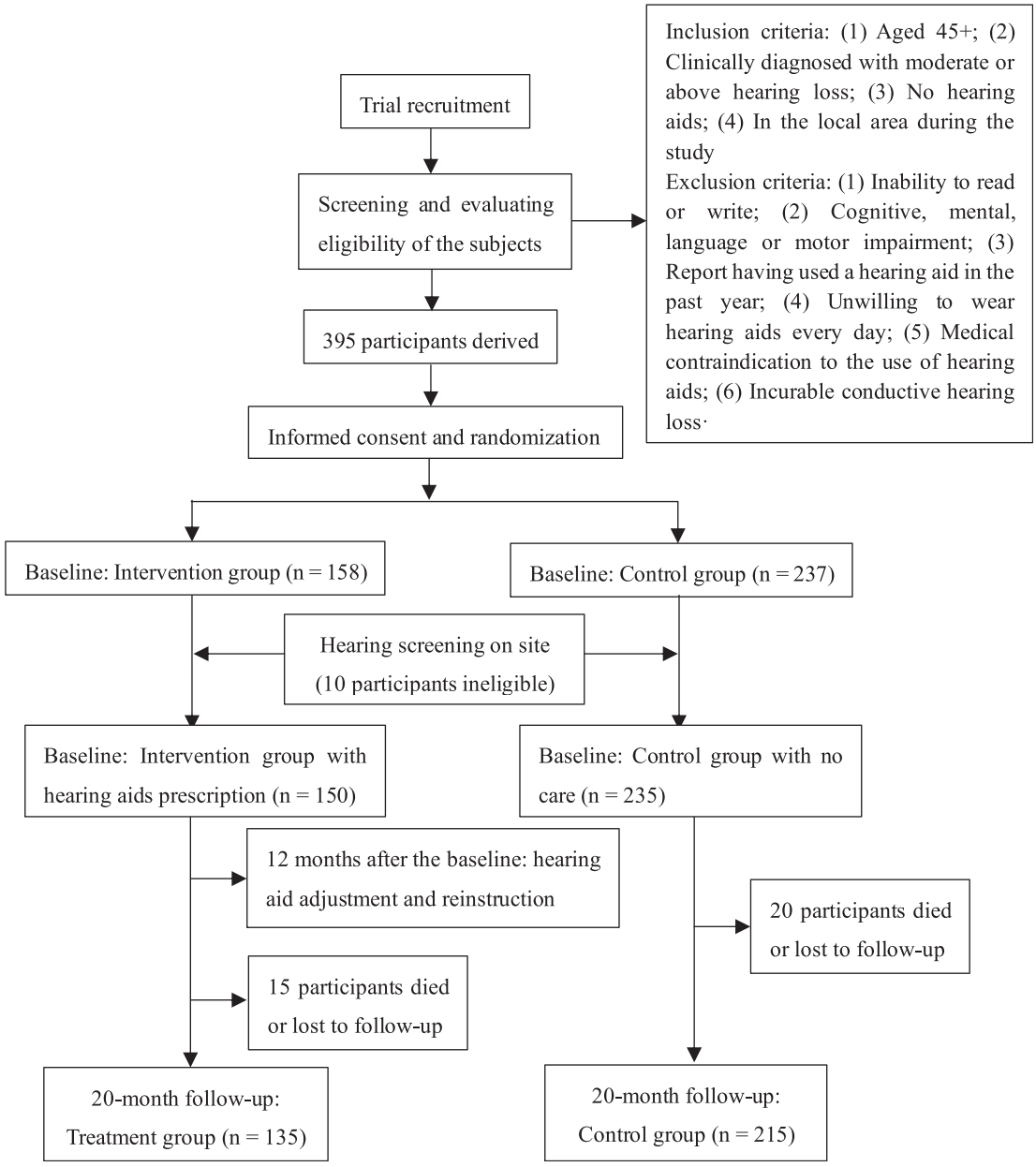

Figure 1. Trial flow diagram for the enrollment and retention of sample.

non-negative data exhibiting substantial positive skewness with heavy tails, and the assumption of normality of the error term is not satisfied, so as to minimize the bias. Model fit for negative binomial regression models and tobit models was assessed by Akaike Information Criterion (AIC) and Bayesian information criterion (BIC). The regression model of DID is as follows:

$$Y_{it} = \beta_0 + \beta_1 \times INTERVENTION_i + \beta_2 \times PERIOD_t + \beta_3 \times (INTERVENTION_i \times PERIOD_t) + \gamma_j X_{it} + \varepsilon_{it}$$

Where Y_{it} is the outcome variable for an individual i in the period t; For outcomes of healthcare costs, we take the log of the cost; $INTERVENTION_i$ is a dummy variable, with 1 denoting the individual receiving intervention; otherwise it is 0; $PERIOD_t$ is the dummy variable for the time period, which is 1 if the intervention is implemented, and 0 if not; the coefficient β_3 for the treatment × time interaction measures the average treatment effect (ATE) of the intervention, which is the change in healthcare utilization/costs beyond that expected over time; X_{it} is a set of covariates.

To examine consistency of treatment effects across key subgroups, we further explored the heterogeneity of people with restricted or active social network and the heterogeneity between middle-aged and older adults through subgroup analysis. We fit separate models for each subgroup variable (e.g., social network, age groups), testing both for the significance of treatment effects within subgroups defined by that variable and whether these effects differed between subgroups by including the appropriate interaction terms between the subgroup, time, and the treatment effect.

As there were few significant differences between respondents with complete exposure and those lost to follow up with respect to the measured characteristics (Supplementary Table 3), we therefore assumed that unobserved data were missing at random (MAR). Thus those missing follow-up data were not included in the model, and we analyzed only those with observed outcome data (complete case analysis), which produced unbiased estimation.[48]

Healthcare costs were reported in yuans in the questionnaire at first (Supplementary Table 4), then they were adjusted to 2021 US dollars using the health care component of the Consumer Price Index (CPI) provided by the National Bureau of Statistics (exchange rate at baseline: 1 US dollars = 6.79 yuan; exchange rate at follow-up: 1 US dollars = 6.47 yuan).[49] Analysis was performed on an "intention-to-treat" (ITT) basis. Stata version 16 (Stata Corporation, College Station, TX) was used for all analyses.

Ethics approval and consent to participate

The ethics application for collecting data on human subjects was approved and updated annually by Peking University's Institutional Review Board (No: IRB00001052-19046). All participants provided written informed consent.

Role of the funding source

The funders played no roles in study design, data collection, data analysis, interpretation, writing of the report.

Results

Table 1 shows the descriptive analysis for the baseline sample. Of the middle-aged and older adults, 66.75% were aged 65 years and above. Male sample accounted for 70.39%, and 93.51% of the sample's household registration was rural. Nearly 70% of the sample had severe or profound hearing loss. 26.23% of the sample had restricted social network. It was worth noting that, male were about three times as likely as female. To examine the effects of sex on the results, we have compared the ATE in models with and without controlling for sex (Supplementary Table 5). It could be seen that sex did not affect the results as the ATEs in model 1 and 2 were similar.

Table 2 shows the differences in healthcare utilization and costs between the intervention group and the control group at baseline and follow-up. The mean number of outpatient visits in the past year was 4.61 at baseline and 6.45 at follow-up. The mean number of inpatient visits in the past year for the baseline sample was 0.62 and 0.57 at follow-up. For healthcare costs, the baseline total healthcare cost was USD $1579, of which the total OOP cost was USD $955. The follow-up total healthcare cost was USD $1736, and the total OOP cost was USD $909. To be exact, the baseline outpatient cost was USD $571, and the follow-up outpatient cost was USD $916. The baseline inpatient cost was USD $904, and the follow-up inpatient cost was USD $745. The baseline self-medication cost was USD $100, and the follow-up self-medication cost was USD $40.

Table 3 shows the differences in healthcare utilization and costs between the intervention group and the control group at the baseline and follow-up survey from DID. For all outcomes variables, negative coefficients indicated that the intervention led to less healthcare utilization or fewer healthcare costs. The hearing aid intervention significantly reduced total healthcare costs (ATE = −1.26, 95% CI = −2.39, −0.14, $p = 0.028$) and total OOP healthcare costs (ATE = −1.29, 95% CI = −2.37, −0.20, $p = 0.021$). To be exact, the hearing aid intervention had no impacts on the number of outpatient (ATE = −0.38, 95% CI = −1.19, 0.44, $p = 0.363$) or inpatient visits (ATE = 0.13, 95% CI = −0.31, 0.57, $p = 0.562$), as well as outpatient (ATE = −0.18, 95% CI = −1.13, 0.76, $p = 0.702$; ATE = −0.26, 95% CI = −1.15, 0.63, $p = 0.571$) or inpatient costs (ATE = −0.19, 95% CI = −1.27, 0.89, $p = 0.735$; ATE = −0.29, 95% CI = −1.30, 0.73, $p = 0.581$). It actually reduced self-medication costs (ATE = −0.82, 95% CI = −1.49, −0.15, $p = 0.016$) and its OOP costs (ATE = −0.84, 95% CI = −1.46, −0.21, $p = 0.009$).

In Table 4, the DID method was used to test the heterogeneity in healthcare costs of samples by social network and age groups. The impacts of the hearing aid intervention on self-medication costs (ATE = −0.26, 95% CI = −0.50, −0.01, $p = 0.041$), and OOP self-medication costs (ATE = −0.27, 95% CI = −0.52, −0.01, $p = 0.038$) varied by social network. Also the impacts on self-medication costs (ATE = −0.22, 95% CI = −0.40, −0.04, $p = 0.019$), and OOP self-medication costs (ATE = −0.17, 95% CI = −0.29, −0.04, $p = 0.010$) varied by age groups. Other outcomes of healthcare utilization and costs did not manifest significant differences between subgroups.

For individuals who had active social network, the hearing aid intervention significantly reduced total healthcare costs (ATE = −1.34, 95% CI = −2.66, −0.01, $p = 0.048$), total OOP healthcare costs (ATE = −1.47,

Characteristics	Total sample (*N* = 385)	Intervention group (*N* = 150)	Control group (*N* = 235)
Age, N (%)			
45–64 years	128 (33.25)	54 (36.00)	74 (31.49)
65+ years	257 (66.75)	96 (64.00)	161 (68.51)
Sex, N (%)			
Male	271 (70.39)	107 (71.33)	164 (69.79)
Female	114 (29.61)	43 (28.67)	71 (30.21)
Household registration, N (%)			
Rural	360 (93.51)	137 (91.33)	223 (94.89)
Urban	25 (6.49)	13 (8.67)	12 (5.11)
Levels of education, N (%)			
Illiterate	179 (46.49)	65 (43.33)	114 (48.51)
Primary	130 (33.77)	59 (39.34)	71 (30.21)
Secondary and above	76 (19.74)	26 (17.33)	50 (21.28)
Marital status, N (%)			
Single/widowed	89 (23.12)	45 (30.00)	44 (18.72)
Married/cohabited	296 (76.88)	105 (70.00)	191 (81.28)
Work types, N (%)			
Non-agriculture	24 (6.23)	11 (7.33)	13 (5.53)
Agriculture	190 (49.35)	69 (46.00)	121 (51.49)
Unemployed	171 (44.42)	70 (46.67)	101 (42.98)
Life sources, N (%)			
Only rely on themselves	54 (14.03)	16 (10.67)	38 (16.17)
Have support from others	331 (85.97)	134 (89.33)	197 (83.83)
Health insurance, N (%)			
No	15 (3.90)	3 (2.00)	12 (5.11)
Yes	370 (96.10)	147 (98.00)	223 (94.89)
Severity of hearing impairment, N (%)			
Moderate	114 (29.61)	45 (30.00)	69 (29.36)
Severe	144 (37.40)	56 (37.33)	88 (37.45)
Profound	127 (32.99)	49 (32.67)	78 (33.19)
Chronic diseases, N (%)			
No	101 (26.23)	46 (30.67)	55 (23.40)
Yes	284 (73.77)	104 (69.33)	180 (76.60)
Smoking status, N (%)			
Current smoking	123 (31.95)	43 (28.67)	80 (34.04)
Ever smoking	64 (16.62)	29 (19.33)	35 (14.90)
Never smoking	198 (51.43)	78 (52.00)	120 (51.06)
Drinking status, N (%)			
Current drinking	112 (29.09)	43 (28.67)	69 (29.36)
Ever drinking	71 (18.44)	30 (20.00)	41 (17.45)
Never drinking	202 (52.47)	77 (51.33)	125 (53.19)
Social network, N (%)			
Active	284 (73.77)	113 (75.33)	171 (72.77)
Restricted	101 (26.23)	37 (24.67)	64 (27.23)

***Table 1*: Baseline characteristics of hearing-impaired middle-aged and older adults aged 45+ by group assignment.**

95% CI = −2.76, −0.17, p = 0.026), self-medication costs (ATE = −0.86, 95% CI = −1.61, −0.10, p = 0.027), and OOP self-medication costs (ATE = −0.90, 95% CI = −1.60, −0.20, p = 0.012). For individuals with restricted social network, the intervention had no impacts on healthcare utilization or costs (Supplementary Table 6). For middle-aged adults aged 45–65, the hearing aid intervention significantly reduced self-medication costs (ATE = −0.97, 95% CI = −1.74, −0.20, p = 0.014) and OOP self-medication costs (ATE = −1.02, 95% CI = −1.73, −0.31, p = 0.005). For older adults aged 65+, the intervention had no impacts on healthcare utilization or costs (Supplementary Table 7).

Healthcare utilization and costs	Total sample (*N* = 385)	Intervention group (*N* = 150)	Control group (*N* = 235)
Number of outpatient visits, mean (SD)			
Baseline	4.61 (0.64)	4.48 (0.80)	4.70 (0.91)
Follow-up	6.45 (0.85)	5.87 (1.14)	6.81 (1.18)
Number of inpatient visits, mean (SD)			
Baseline	0.62 (0.05)	0.57 (0.08)	0.66 (0.07)
Follow-up	0.57 (0.06)	0.57 (0.10)	0.57 (0.07)
Total healthcare costs (USD$), mean (SD)			
Baseline	1579 (369)	1295 (381)	1762 (556)
Follow-up	1736 (329)	1535 (471)	1866 (448)
Total OOP healthcare costs (USD$), mean (SD)			
Baseline	955 (229)	922 (354)	975 (301)
Follow-up	909 (161)	799 (228)	981 (221)
Outpatient costs (USD$), mean (SD)			
Baseline	571 (185)	641 (351)	526 (205)
Follow-up	916 (283)	693 (349)	1057 (406)
OOP outpatient costs (USD$), mean (SD)			
Baseline	426 (159)	516 (335)	367 (149)
Follow-up	448 (135)	361 (153)	503 (198)
Inpatient costs (USD$), mean (SD)			
Baseline	904 (310)	574 (109)	1115 (503)
Follow-up	745 (106)	822 (185)	695 (127)
OOP inpatient costs (USD$), mean (SD)			
Baseline	444 (150)	346 (71)	507 (243)
Follow-up	407 (58)	423 (99)	397 (72)
Self-medication costs (USD$), mean (SD)			
Baseline	100 (32)	80 (20)	113 (51)
Follow-up	40 (13)	15 (7)	56 (21)
OOP self-medication costs (USD$), mean (SD)			
Baseline	81 (31)	60 (18)	95 (50)
Follow-up	36 (13)	13 (6)	51 (20)

***Table 2*: Baseline and follow-up characteristics of healthcare utilization and costs (USD$) in a year among hearing-impaired middle-aged and older adults aged 45+ by group assignment.**

Discussion

To our knowledge, our study is the first to explore causal impacts of the hearing aid intervention on healthcare utilization and costs so far. Using a RCT conducted in rural China, we found that among 385 eligible participants aged 45+, the hearing aid intervention significantly reduced total healthcare costs and self-medication costs. It was partly consistent with a U.S. study that hearing-impaired individuals who used hearing aids had lower annual medical costs.[28] Later studies also revealed that hearing aids helped to reduce medical service utilization for people with hearing loss.[30,50] In contrast, another study used a cohort of 1336 older adults with self-reported hearing impairment from the US Medicare database and found that wearing hearing aids was associated with increased total Medicare expenditures and OOP costs.[26] Causes for the differences may be that objects of the US study were those seeking to wear hearing aids actively. They paid more attention to their health, and had a higher willingness to pay for healthcare services. However, our intervention was to provide free hearing aids for those with hearing impairment, whose willingness to pay for the healthcare services might be lower.

The decrease in total healthcare costs was mainly reflected in the decrease in self-medication costs. Self-medication refers to practice of taking drugs, herbs or home remedies voluntarily, or on the advice of others without consulting a doctor.[51] It often provides a cheap and convenient solution to curing minor illnesses, which can rapidly meet people's demand and thus being increasingly popular in China.[52] For our study subjects, the rural populations, it is an even more common practice to treat mild illnesses for three possible reasons. First, due to the rapid inflation in the price of professional medical services, many rural populations cannot afford such high medical expenditures and have to use low-cost drugs to treat their illnesses.[53] Second, in rural areas, long distances from specialized health institutions and poor quality of health services at

Healthcare utilization and costs	DID		
	ATE[c]	95% CI	*p* value
Number of outpatient visits [a]	−0.38	−1.19, 0.44	0.363
Number of inpatient visits [a]	0.13	−0.31, 0.57	0.562
Total healthcare costs (USD$)[b]	−1.26	−2.39, −0.14	0.028
Total OOP healthcare costs (USD$)[b]	−1.29	−2.37, −0.20	0.021
Outpatient costs (USD $)[b]	−0.18	−1.13, 0.76	0.702
OOP outpatient costs (USD$)[b]	−0.26	−1.15, 0.63	0.571
Inpatient costs (USD$)[b]	−0.19	−1.27, 0.89	0.735
OOP inpatient costs (USD$)[b]	−0.29	−1.30, 0.73	0.581
Self-medication costs (USD$)[b]	−0.82	−1.49, −0.15	0.016
OOP self-medication costs (USD$)[b]	−0.84	−1.46, −0.21	0.009

***Table 3*: Differences in healthcare utilization and costs between intervention and control groups during baseline and follow-up hearing surveys (*N* = 385).**

[a] Binomial regression models for outcome variables of healthcare utilization.

[b] Tobit regression models for outcome variables of healthcare costs.

[c] ATE means the treatment × time coefficient, which is the change in healthcare utilization/costs beyond that expected over time.

All models adjusted for age, sex, household registration, education, marital status, work types, life sources, health insurance, severity of hearing impairment, chronic diseases, smoking status, drinking status, and social network.

community health centers further impeded them from seeking professional healthcare services.[54] Third, limited insurance coverage has, to some degree, promoted the practice of self-medication.[54]

The reduction in self-medication costs due to wearing hearing aids may reflect improved overall health. As those prescribed with hearing aids had high compliance, and a majority of them perceived benefits from it, it can further lead to improvements in hearing-related quality of life and alleviation of depressive symptoms.[55] Due to better communication, those wearing hearing aids may be more aware of their health conditions and avoid unnecessary self-medication costs.[56] In addition, patients can better understand and adhere to the recommended treatment methods, thus improving their health status and reducing incidence of minor illnesses.[57] As for outpatient or inpatient healthcare services, on the one hand, they are not of highest priority for most rural populations[58]; on the other hand, wearing hearing aids cannot help much in reducing serious diseases that need professional healthcare.[5] Therefore, outpatient or inpatient healthcare services can be less sensitive to the hearing aid intervention and did not show significant changes in our trial.

The results of heterogeneity analysis showed that impacts of the hearing aid intervention on self-medication costs varied with social network and age groups. For individuals who had active social network, the hearing aid intervention reduced total healthcare costs, self-medication costs and their respective OOP costs. However, the hearing aid intervention had no effects on healthcare utilization or costs for individuals who had restricted social network. For different age groups, the

Healthcare utilization and costs	By social network			By age groups		
	ATE[c]	95% CI	*p* value	ATE[c]	95% CI	*p* value
Number of outpatient visits[a]	0.44	−2.07, 2.94	0.732	0.01	−2.06, 2.07	0.999
Number of inpatient visits[a]	−0.23	−1.29, 0.83	0. 672	−0.41	−1.42, 0.59	0.421
Total healthcare costs (USD$)[b]	−0.81	−3.48, 1.87	0.555	0.38	−2.09, 2.85	0.763
Total OOP healthcare costs (USD$)[b]	−0.92	−3.48, 1.63	0.477	0.25	−2.13, 2.63	0.835
Outpatient costs (USD$)[b]	0.50	−1.60, 2.61	0.639	−0.61	−1.67, 0.46	0.127
OOP outpatient costs (USD$)[b]	0.03	−1.97, 2.03	0.977	−0.36	−1.29, 0.58	0.170
Inpatient costs (USD$)[b]	−0.29	−2.88, 2.30	0.827	0.39	−1.98, 2.75	0.748
OOP inpatient costs (USD$)[b]	−0.29	−2.70, 2.13	0.817	0.52	−1.70, 2.74	0.646
Self-medication costs (USD$)[b]	−0.26	−0.50, −0.01	0.041	−0.22	−0.40, −0.04	0.019
OOP self-medication costs (USD$)[b]	−0.27	−0.52, −0.01	0.038	−0.17	−0.29, −0.04	0.010

***Table 4*: Differences in health utilization and costs between intervention and control groups during baseline and follow-up hearing surveys, by social network and age groups.**

[a] Binomial regression models for outcome variables of healthcare utilization.

[b] Tobit regression models for outcome variables of healthcare costs.

[c] ATE means the treatment × time × subgroup coefficient, which is the change in healthcare utilization/costs between subgroups beyond that expected over time.

All models adjusted for age, sex, household registration, education, marital status, work types, life sources, health insurance, severity of hearing impairment, chronic diseases, smoking status, and drinking status.

effects of the hearing aid intervention in reducing self-medication costs were only manifested in middle-aged adults aged 45–64. The reason can be that, those with active social network or younger age may have a stronger desire to interact and communicate with others. Hearing aids greatly reduce their communication barriers, which is conducive to the improvement of overall health conditions and the reduction in the incidence of minor diseases, therefore reducing their healthcare costs.[59] Besides, they are more likely or capable to seek suitable drugs that meet their demands due to enhanced social network[60] or relatively young age,[61] thus avoiding unnecessary self-medication costs and decreasing their daily healthcare expenses to some extent.[26]

Our longitudinal study made an important contribution to the literature by considering the role of hearing aids in preventing or minimizing healthcare utilization and costs, which was seldom done in previous studies.[62] It also addressed the limitations of previous studies in that, rather than using self-reported hearing status as most hearing-relevant studies did,[62,63] we measured the hearing status by using clinical diagnostic of hearing loss, which could accurately reflect the objective hearing status. In addition, there is difficulty in the interpretation of many existing observational studies examining how the hearing aid treatment changes healthcare utilization and costs, because hearing aids are relatively underutilized and may be confounded with factors that also change healthcare utilization and costs. We utilized a randomized controlled design, which ensured both observables and unobservables were on average the same between treatment and control, and minimized the risk of bias by confounding variables. Also, the trial had a high follow-up rate of more than 87%, thus adding to confidence in the results. What's more, we conducted heterogeneity analysis by social network and age groups, which could help reach a much deeper understanding of the factors influencing the intervention, and what results to expect next time the intervention is implemented.

Limitations must be acknowledged. First, we only selected sample from two counties in Linyi City, Shandong Province, which might induce selection bias and affect the results. Second, asking participants to retrospectively self-report health service utilization might cast doubt on the accuracy of the health service utilization data, especially among older adults. Third, the exact mechanism underlying the causal relationship between the hearing aid intervention and healthcare costs has not been validated. Fourth, as the follow-up survey was conducted 20 months after the baseline and the outcomes were measured within a time dimension of one year, it was not clear whether the hearing aid had a favorable average treatment effect over the entire 20 months of costs or not. Fifth, as there is a wide range of hearing aids on the market, the impacts of other types of hearing aids is an important subject to be explored. Additionally, the study does not delve into the type of self medication being reduced, which could potentially give a pointer about the impact of unaddressed hearing loss.

In conclusion, our study examined impacts of the hearing aid intervention on healthcare utilization and costs among middle-aged and older people aged 45+ in rural China. Our results indicated that hearing aids use significantly lowered self-medication costs and total healthcare costs, especially among those with active social network or older age. It can be speculated that hearing aid use would improve the overall health of hearing-impaired patients and reduce their daily healthcare expenses. The intervention of fitting hearing aids earlier and promoting their social network is expected to be adapted to other similar settings in developing countries facing the problem of untreated hearing impairment, and reduce healthcare burden associated with hearing impairment.

Contributors

PH, DZ, and XY conceived and designed the study. XY, DZ, and PH conducted data analysis, drafted and revised the manuscript. JG, YD, JW, HZ, XS helped collect the data. PH, DZ, YW, and SC helped design the analytic strategy, and verified the underlying data. PH supervised all aspects of this study. All authors critically revised the article and approved the final manuscript.

Data sharing statement

The data analyzed during the current study are available from the corresponding author on reasonable request.

Declaration of interests

We declare no competing interests.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.lanwpc.2022.100594.

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