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Effects of graphene far-infrared and social network interventions on depression, anxiety and dementia in older adults

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Abstract

Background Five-guaranteed elderly individuals are a special group of the elderly Chinese population faced with unique challenges; these individuals lack any financial resources (including support by relatives), and are solely reliant on the government to provide food, clothing, medical care, and housing as well as burials. In this article, we aim to investigate mood problems (depression, anxiety) and cognitive functioning in Five-guaranteed elderly individuals, and to validate the effectiveness of two promising interventions, graphene far-infrared intervention (GFII; an exploratory and noninvasive technique) and social network intervention (SNI), for elderly people to lay the foundation for future social service work.

Methods To address the emotional and cognitive difficulties experienced by this special group, we designed this study, which is the first to apply GFII in this population. We also administered SNI given the social isolation of these individuals, in addition to a corresponding control group. 108 elderly individuals in 3 elder care facilities were screened to evaluate eligibility to participate in the current study, including 44 from Facility A (allocated to the GFII group), 43 from Facility B (allocated to the SNI group), and 21 from Facility C (allocated to the control group). GFII lasts for four weeks, with professionally trained carers putting on and removing intervention caps for half an hour each day. SNI lasts for three weeks, three times a week, and consists of a total of nine themed activities. The length of an activity is 90 min. We also did pre- and post-test comparisons of depression, anxiety and cognition in each group of older adults.

Results The results showed that GFII led to immediate improvements in anxiety and cognitive impairment in the five-guaranteed elderly individuals, and the improvement in cognitive function was sustained over time. Moreover, SNI group showed significant improvements in cognitive function after the intervention period.

Conclusions The GFII is a promising intervention that can be applied to intervene in cognitive and mood disorders in older adults. The GFII has short-term interventions for anxiety in older adults, but long-term effects for cognitive impairment. SNI also had an interventional effect on cognition.

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Background

With recent decreases in fertility, increases in longevity, and the aging of large population cohorts, population aging is becoming a global issue. The world is in the midst of an unprecedented transition of the global population [1]. Today, elderly individuals aged 60 years and older account for 20.4% of the Chinese population, and this rate is expected to exceed 30% in 2035; thus, China will transition into a super-aged society [2]. As population aging has received global attention, ensuring the livelihood and well-being of elderly individuals and attending to their survival needs have become important issues. China has long since implemented national-level preparations for population aging, drawing attention to a series of research topics. In 2021, the National Health and Aging Administration issued the Notice on Comprehensively Strengthening Health Services for the Elderly [3], which mentions that perspectives on the physical and mental health of elderly individuals have shifted from "disease-centered" to "health-centered" (i.e., that pursuing healthy aging is the least costly and most effective means of actively responding to population aging). This notice also proposes the provision of psychological counseling, emotional relief, and bereavement support for elderly individuals. The National Health and Wellness Commission also released the "14th Five-Year Plan for Healthy Aging" in 2022 [4], proposing nine tasks, such as improving the preventive healthcare service system, that emphasize both physical and mental health.

Five-guaranteed elderly individuals

In rural China, however, there is a group of older people who portray the extreme existential plight of elderly individuals. These individuals have no children at the moment. Some of the reasons why they never married or lost their spouses are as follows: were born in a period of poverty, when their families experienced financial difficulties, and not in a position to get married; or were the older children in their families and had too many siblings thus, they were too old to marry after arranging for the marriages of their younger siblings. In their old age, these people can no longer work, have no stable source of income and have no legal benefactor; therefore, the state provides them with shelter, money and materials to meet their basic needs. These individuals are known as "five-guaranteed elderly individuals", i.e., elderly people who are supported by the state, which provides five benefits (food, clothing, medical care, shelter and burial) [5]. Given this lack of social support, this group faces serious mental health problems. For example, a statistical survey of the five-guaranteed elderly individuals in Anhui Province, China, revealed that the "five guarantees" of this population, especially medical care, may not be entirely guaranteed. In addition, they experience low levels of support and poor living conditions. All of these factors contribute to the low level of life satisfaction of five-guaranteed elderly individuals [6]. Another survey on cognitive function and depression in five-guaranteed elderly individuals in Guangxi Province, China, showed that these older adults had much higher levels of depression and cognitive impairment than other groups; that cognitive functioning, in particular, was impaired; and that depressed mood may have affected cognitive functioning [7]. Specifically, the prevalence rates of cognitive dysfunction and depression among five-guaranteed elderly individuals reached 46.6% and 30.9%, respectively. Five-guaranteed elderly individuals may be the group with the most extreme survival difficulties among the elderly population, and it is very important to provide effective interventions for psychological problems and to provide psychological services. Additionally, the intervention methods applicable for this population are likely also applicable for the general elderly population.

Social network interventions (SNIs)

We reviewed previous intervention methods used in elderly individuals and found that although pharmacological and psychotherapeutic interventions, either alone or in combination, are effective for treating mental illness in elderly individuals, there are some problems with both types of treatments [8]. Considering the long-term social isolation experienced by five-guaranteed elderly individuals during the COVID-19 pandemic, we believe that social network-based interventions may be effective, as interpersonal psychotherapy has received the most empirical support that it is an effective psychological intervention for the treatment of late-life depression of such psychotherapies [8]. Network interventions are developed with the aim of accelerating behavior change and generating, accelerating or sustaining human behaviors and positive health outcomes [9]. Research involving social network techniques is increasingly showing that strengthening social networks is an effective and sustainable way to improve individuals' performance and change their health-related behaviors [10, 11]. The effectiveness of social network interventions (SNIs) in the elderly population has been confirmed [12].

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Graphene far-infrared intervention (GFII)

Physical and mental health go hand in hand, and this is especially true for older adults [13]. In addition to SNIs that can enhance older adults' networks and thus improve their mental health, physical interventions may also be effective. In contrast to pharmacological and psychotherapeutic interventions, which have potential negative effects (such as side effects and cultural maladjustment), photobiomodulation (PBM) is a promising technique [8]. Recent advances in graphene-based science and technology have revealed exciting possibilities for psychological interventions. Specifically, graphene films (GFs) can emit radiant heat in a the far-infrared spectrum (4–14 μm), which matches well with that of the human body (8–14 μm) [14]. This alignment implies that radiant heat generated from GFs has a resonant effect when applied to living subjects, which is expected to permit deeper penetration and more homogeneous energy delivery into tissues [15]. Previously, some studies have shown that far-infrared radiation has a beneficial effect on physical and mental health [16, 17]. Far-infrared radiation can protect against sleep disorders, depression, stress, behavioral sensitization and memory impairment [17]. Recent research has indicated that exposure to far-infrared radiation may have beneficial biological effects in mouse models of Alzheimer's disease (AD) [18]. A far-infrared low-temperature sauna (FILTS) program effectively improved geriatric syndrome and frailty symptoms [19]. However, the far-infrared sauna used in the FILTS program reached a temperature of 60 ℃, and the human body cannot be exposed to this environment for long periods. GFs, which convert electric energy into light energy and only reach a temperature of 40 ℃, can address this shortcoming. It has been shown that Whole-body hyperthermia at 38.5 °C holds promise as a safe, rapid-acting, antidepressant modality with a prolonged therapeutic benefit [20]. In addition, GFs are manufactured using a special process that allows controlled dimensions and characteristic flexibility [15], and graphene can easily be cut into customized sizes for different usage scenarios, such as a graphene cap.

The present study

Our aim was to investigate the mental health (depression, anxiety, and cognitive function) of five-guaranteed elderly individuals and to provide them with an appropriate intervention. Additionally, we hoped to validate the effectiveness of two promising intervention methods, the SNI and graphene far-infrared intervention (GFII), for elderly people to lay the foundation for future social service work. We expected that after the intervention, the participants in the GFII group and those in the SNI group would demonstrate better overall mood and cognitive functioning than those in the control group.

Methods

Study design

The study design and procedures were approved by the ethics review committee of the Institute of Psychology, Chineae Academy of Science. This study is part of the national mental health improvement and intervention plan for elderly individuals. We conducted a survey of the basic characteristics and mental health of elderly individuals in 9 elder care facilities in rural Hefei, Anhui, China, from July 20 to August 2, 2022. This intervention study was a cluster-randomized controlled trial in which 3 groups were established to examine the effects of the GFII, SNI and a control condition on depressive symptoms, anxiety symptoms and cognitive impairment in elderly individuals. The SNI commenced on August 5 and ended on August 24. During this three-week period, group activities were held on Monday, Wednesday and Friday, for a total of 9 sessions. After the intervention, outcomes were assessed on August 24 and 25. The GFII commenced on August 12, 2022, and lasted for four weeks, with half an hour per day, and outcomes were assessed after 2 weeks and 1 month. The outcomes of the control group were assessed on August 26. The durations of the two interventions were not consistent because they were not comparable in terms of frequency and intensity; we implemented the two interventions independently and wished to test their respective effects. The application of graphene far-infrared to psychological interventions for elderly people is unprecedented and there is no study design to refer to, so we referenced previous infrared studies to determine the measurement time point and frequency [20]. The study design for the SNI intervention was informed by published research [21]. After the assessment, we provided participants with free physical examinations and one-on-one psychological counseling services. We also provided all elderly individuals in the 3 groups with cake to express our gratitude after the last assessment. Standardized treatment protocols, training manuals, and fidelity checklists were developed for each intervention.

Participants

A total of 239 residents from 9 elder care facilities in rural Hefei were surveyed (see Fig. 1). These 9 facilities for the elderly are essentially the same, in a county not far from each other, and they are all set up by the government to solve the problem of elderly care for widows and orphans. Among the 9 elder care facilities, there were 2 large elder care facilities, with approximately 40 elderly individuals participating in our survey, and 7 smaller elder care facilities, with approximately 20 elderly people participating. Considering the expected rate of drop out during the intervention, we chose the two large elder care facilities to serve as the intervention groups and
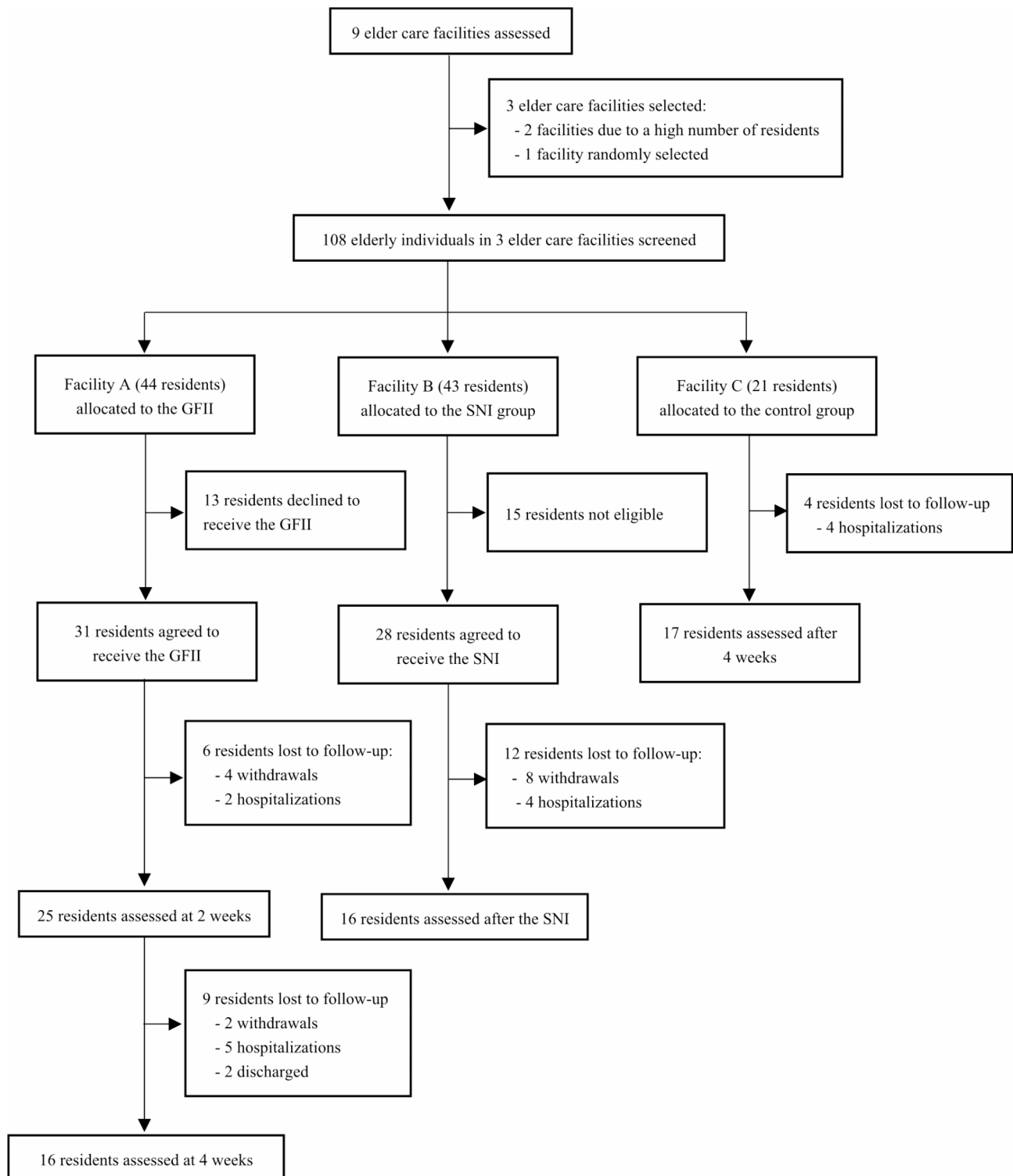
Fig. 1 Recruitment and follow-up of elder care facility residents
Notes: Elder care facility (cluster). GFII = graphene far-infrared intervention. SNI = social network intervention

randomly selected one of the other 7 elder care facilities to serve as the control group; thus, 108 elderly individuals in 3 elder care facilities were screened to evaluate eligibility to participate in the current study, including 44 from Facility A (allocated to the GFII group), 43 from Facility B (allocated to the SNI group), and 21 from Facility C (allocated to the control group). There were no special inclusion criteria for the intervention, as each of the

elderly living in the elder care facility was an five-guaranteed elderly individual, and their age and basic conditions met the requirements of the study. When screening subjects, all three groups excluded elderly people with a history of mental illness. The GFII group excluded elderly people with cardiovascular disease and hypertension because they had to wear caps that would heat up to 40 °C. The social network had no additional exclusion criteria. In addition, subjects who were hospitalized due to illness and left the elder care facility during the intervention were also excluded. Subjects in all three groups could withdraw at any time if they did not want to continue participating in the intervention. Prior to the intervention, we also ensured that there were no differences in mental health and cognitive levels between the three groups at baseline (see Table 1).

Interventions

The GFII involved the use of a custom-made graphene therapy cap (see Fig. 2).

The cap consisted of 3 parts: the main body of the cap, the thermostat and the power adapter. One end of the thermostat was connected to the main body of the cap, and the other end was connected to the power adapter; the adapter was plugged into a 220 V household power outlet. This turned on the cap, and the temperature could be adjusted. The light energy conversion rate of the graphene coating material used in the cap reached 90%,

generating a temperature of 40 °C. Five caregivers were responsible for providing care for the elderly individuals. We provided standardized training on the GFII to these 5 caregivers. Each caregiver was responsible for assisting with the intervention of the elderly individuals that they usually cared for. At 10:00 a.m. each day, they went to the elderly individual's room and helped them to don the cap, which was set at 40 °; after half an hour, the caregiver helped them remove the cap. We did not interfere with the behavior of the elderly individual while wearing the cap; he or she could sit, lie down or do whatever activities desired within the length of the power line.

GFII has no side effects and is non-invasive and harmless [22]. During the intervention, we asked the caregivers to keep an eye on the elderly for any adverse reactions, which were not found. At the end of the intervention, we conducted an interview with all the elderly to find out their feelings or discomfort during the intervention, and the elderly did not report any discomfort except for a little bit of heat. On the left and right sides of the graphene cap, there is a piece of graphene in the shape of a thin slice. The cost of customizing a graphene cap mainly includes graphene material, graphene material labor processing fee, cap accessories, adapters, temperature controllers and so on. Since the cap is a lab product and has not yet reached mass production, the cost of a cap is about RMB 300. If the cap can be mass-produced in the future, the cost can be further reduced.

Table 1 Baseline characteristics

	Total	GFII	SNI	Control	F	χ^2	*p* value
Residents enrolled	80	31	28	21			
Sex						1.179	0.555
Female	7 (8.7%)	4 (12.9%)	2 (7.1%)	1 (5.0%)			
Male	73 (91.3%)	27 (87.1%)	26 (92.9%)	20 (95.0%)			
Age, years	78.14 (7.17)	79.77 (6.46)	75.86 (8.09)	78.67 (6.55)	2.330		0.104
Marital status						5.304	0.505
Single or unmarried	51 (63.0%)	17 (54.8%)	20 (71.4%)	13 (61.9%)			
Married	18 (22.2%)	9 (29.0%)	4 (14.3%)	5 (23.8%)			
Separated or divorced	3 (3.7%)	0	2 (7.1%)	1 (4.8%)			
Widowed	9 (11.1%)	5 (16.1%)	2 (7.1%)	2 (9.5%)			
Education level						**14.749**	**0.005**
Never attended school	40 (49.4%)	15 (48.4%)	10 (35.7%)	14 (66.7%)			
Primary education	32 (35.5%)	13 (41.9%)	17 (60.7%)	2 (9.5%)			
Secondary education or more	9 (11.1%)	3 (9.7%)	1 (3.6%)	5 (23.8%)			
Probable depression	25 (30.9%)	7 (22.6%)	13 (46.4%)	5 (23.8%)		4.628	0.099
Probable anxiety	12 (14.8%)	2 (6.5%)	7 (25%)	3 (14.3%)		3.981	0.137
Dementia						1.070	0.899
Alzheimer's disease	32 (39.5%)	13 (41.9%)	13 (46.4%)	6 (28.6%)			
Mild cognitive impairment	37 (45.7%)	16 (51.6%)	12 (42.9%)	9 (42.9%)			
PHQ-9 score	7.18 (6.58)	6.00 (5.06)	9.46 (7.71)	5.86 (6.43)	2.721		0.072
GAD-7 score	4.61 (5.24)	3.87 (3.73)	5.96 (6.43)	3.90 (5.28)	1.449		0.241
s-MoCA score	5.57 (3.58)	5.42 (3.78)	5.29 (3.17)	6.29 (3.95)	0.456		0.636

Notes: Data are n, n (%), or mean (SD). GFII=graphene far-infrared intervention. SNI=social network intervention
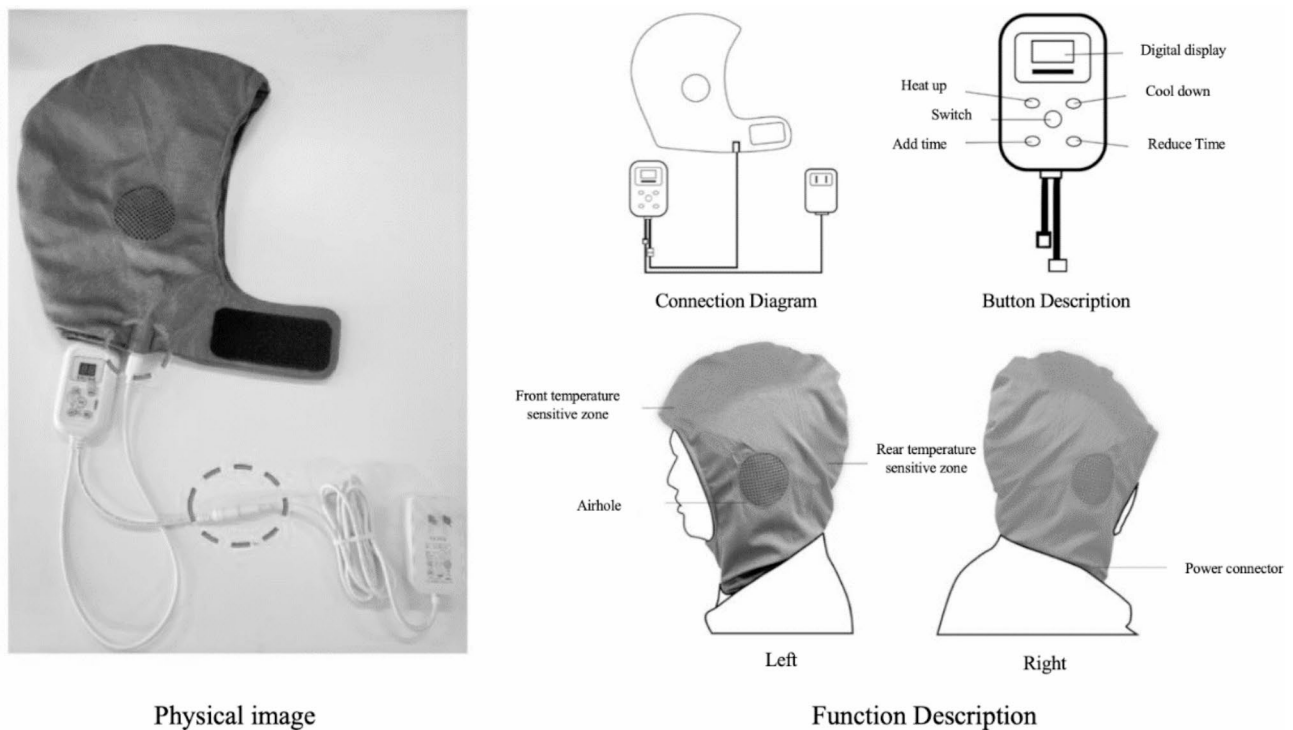
Fig. 2 Picture and description of the custom-made graphene cap

The SNI had the central aim of stimulating or encouraging peer-to-peer interaction to create cascades of information spread or behavioral diffusion. The intervention consisted of 9 face-to-face sessions administered 3 times a week, each lasting 90 min. Each event had a different theme and we designed different activities for each theme. The themes of the nine events were: getting to know each other, companionship, thanksgiving, children's fun, pride, growth, celebration, hope, and farewell. The activity was uniformly designed by a PhD in Psychology as the lead intervenor. Considering the need to communicate with the elderly in the local dialect, the specific implementation was carried out by the caregivers and local volunteers as intervenors. In order to ensure the quality of the intervention, all the intervenors participated in a two-hour training and rehearsal meeting before each intervention session as well as a peer supervision meeting that lasted two hours after each session. The training and rehearsal meeting as well as the peer supervision meeting were led by the lead intervenor, with the aim that each intervenor would be familiar with the content of the intervention and would be able to summarize the problems and experiences and revise them in a timely manner after each intervention activity, and complete the intervention professionally and with high quality.

Measures
Depression was assessed with the Patient Health Questionnaire (PHQ-9), which was compiled by Kroenke et al. [23] and translated into Chinese and revised by Wang et al. [24]. The PHQ-9 contains nine items scored on a scale from 0 (not at all) to 3 (almost every day) based on the self-reported frequency of depressive symptoms in the past 2 weeks. The total score ranges from 0 to 27, and scores above 10 indicate probable depression symptoms [25].

Anxiety was assessed with the Chinese version of the Generalized Anxiety Disorder Scale (GAD-7) [26]. The 7 items are rated on a 4-point scale ranging from 0 (never) to 3 (almost every day) to assess the frequency of anxiety symptoms in the past 2 weeks. The total score ranges from 0 to 21, and according to the established criteria [27], scores above 10 indicate probable anxiety symptoms.

Cognitive function was assessed with the short form of the Montreal Cognitive Assessment (s-MoCA), which was developed by Li [28]. The items are used to examine function in 6 cognitive domains (i.e., visuospatial/executive function, attention, language, abstraction, delayed memory, and orientation). If the number of years of education is less than or equal to 12, the total score is increased by 1 point. The total score ranges from 0 to 18: scores less than or equal to 11 indicate probable mild cognitive impairment (MCI), and scores less than or equal to 4 indicate probable Alzheimer's disease (AD).

Statistical analysis

The data were analyzed using SPSS 26.0. First, descriptive statistics, independent sample t test and one-way ANOVA were used to examine differences in sociodemographic information among groups at baseline. Second, the repeated-measures analysis of covariance was used to analyse randomized controlled trials with baseline and follow-up measurements. Third, the Wilcoxon signed-rank test was used to examine the differences in depression, anxiety and cognitive function between baseline and postintervention in each group, and the results were further validated using a Bonferroni correction to account for multiple comparisons.

Results

Description

Most residents were male (73 [91.3%] of 80) and had a mean age of 78.14 (SD 7.17) years. Most residents were single or unmarried (51 [63.8%] of 80). Half of the residents had never attended school (40 [50%] of 80). Most residents did not have friends at the elder care facility (56 [70%] of 80). According to the cutoff scores, 25 (30.9%) residents had probable depression, 12 (14.8%) had probable anxiety, 32 (39.5%) had probable Alzheimer's disease, and 37 (45.7%) had probable MCI at baseline. The mean PHQ-9, GAD-7 and s-MoCA scores were 7.18 (SD=6.58), 4.61 (SD=5.24) and 5.57 (SD=3.58), respectively. Baseline characteristics were similar across groups except the education level (see Table 1).

Effects of the graphene far-infrared intervention

The results of the repeated-measures ANCOVA indicated a nonsignificant main effect of group and a nonsignificant effect of the time by group interaction. The main effects of time on GAD-7 scores (a: $p=0.013$, $\eta^2=0.108$; b: $p=0.019$, $\eta^2=0.117$) and s-MoCA scores (a: $p=0.022$, $\eta^2=0.094$; b: $p=0.004$, $\eta^2=0.171$) were significant (see Table 2).

The Wilcoxon signed-rank test examining the differences in depression, anxiety and cognitive function between baseline and postintervention in each group is shown in Table 3. After 2 weeks of the GFII, the GAD score (Z=-3.391, $p=0.012$) of elderly individuals were significantly lower than those at baseline, while the s-MoCA score (Z=-3.956, $p=0.001$) was significantly higher than baseline. However, there were no significant differences in anxiety after 4 weeks of the GFII, while the s-MoCA score (Z=-3.417, $p=0.012$) remained significantly higher than the baseline value. The s-MoCA scores also exhibited a significant difference between baseline and postintervention in SNI group, but not in the control group, suggesting that SNI also has a significant effect on intervening in cognitive impairment in older adults and that the practice effect was not significant. Thus, our study found a probable short-term effect of the GFII on anxiety and long-term effects on cognition. SNI also had an interventional effect on cognition. Notably, caution is warranted when interpreting these findings as they represent preliminary results from an exploratory study.

Discussion

In this study, the prevalence rates of depression, anxiety, MCI, and AD among five-guaranteed elderly individuals were 30.9%, 14.8%, 45.7%, and 39.5%, respectively. A 2020 study on rural five-guaranteed elderly individuals showed that the prevalence rates of MCI and depression in this group were 46.6% and 30.9% [29], respectively; although AD in elderly individuals was not examined, prevalence rates of MCI and depression are highly consistent with those of the present study; thus, our findings could reflect the general cognitive function and depression prevalence among five-guaranteed elderly individuals. In terms of depression, there have been few surveys of five-guaranteed elderly individuals, but this group may be comparable with elderly empty nesters. Empty nesters refer to older adults whose children have already left home and

Table 2 Effects estimates from repeated-measures analysis of covariance

		ANCOVA [a]			ANCOVA [b]		
		F	*p* value	η_p^2	F	*p* value	η_p^2
PHQ-9 score	Group	1.350	0.268	0.048	0.964	0.389	0.041
	Time	3.397	0.071	0.059	2.052	0.159	0.044
	Time×Group	0.476	0.624	0.017	0.005	0.995	< 0.001
GAD-7 score	Group	0.453	0.638	0.017	0.108	0.898	0.005
	Time	**6.566**	**0.013**	**0.108**	**5.955**	**0.019**	**0.117**
	Time×Group	0.996	0.376	0.036	0.346	0.710	0.015
s-MoCA score	Group	0.182	0.834	0.007	0.003	0.997	< 0.001
	Time	**5.583**	**0.022**	**0.094**	**9.301**	**0.004**	**0.171**
	Time×Group	1.080	0.347	0.038	2.186	0.124	0.089

Notes: [a] ANCOVA results comparing assessment scores of the 2-week graphene far-infrared intervention group, social network intervention group and control group over time, controlling for education level. [b] ANCOVA results comparing assessment scores of the 4-week graphene far-infrared intervention group, social network intervention group and control group over time, controlling for education level

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Table 3 Effects of within-subject intervention

	GFII (2 weeks: N = 25, 4 weeks: N = 16)							SNI (N = 16)				Control (N = 17)			
	Baseline	2 weeks	Z	p value	4 weeks	Z	p value	Baseline	Post	Z	p value	Baseline	Post	Z	p value
PHQ-9 score	6.00 (4.98)	2.80 (3.12)	-2.655	0.096	4.31 (4.47)	-0.674	1.000	5.06 (4.75)	3.25 (4.85)	-1.015	1.000	6.76 (6.70)	5.12 (5.16)	-0.735	0.462
GAD-7 score	4.00 (3.83)	1.40 (2.16)	-3.391	0.012	2.69 (3.40)	-1.271	1.000	3.13 (4.80)	3.63 (4.70)	-0.579	1.000	4.82 (5.49)	2.47 (5.15)	-1.533	0.125
s-MoCA score	5.64 (3.87)	9.00 (4.24)	-3.956	0.001	10.31 (3.86)	-3.417	0.012	6.00 (3.12)	10.06 (3.53)	-3.322	0.012	6.29 (3.95)	8.53 (4.38)	-2.078	0.456

Notes: Data are the mean (SD). GFII = graphene far-infrared intervention. SNI = social network intervention. 2 weeks = after 2 weeks of the graphene far-infrared intervention. 4 weeks = after 4 weeks of the graphene far-infrared intervention. The *p*-values in the tables are Bonferroni corrected

thus live alone or with their spouse or older parents [30]. A meta-analysis of depression among elderly Chinese empty nesters showed that the prevalence rates of depression for empty nesters and non-empty nesters were 44.2% and 26.3%, respectively [31]. The prevalence of depression among five-guaranteed elderly individuals was much lower than that of the empty nesters but higher than that of the general elderly population. This may be because five-guaranteed elderly individuals don't have spouses around and have no legal benefactor (e.g., relative) to support them. They are accustomed to living in a situation where they must be supported by the government and have no expectation of their children. In contrast, empty nesters may experience a conflict between their expectations of their children and the reality of their situation, inducing depression. Regarding the prevalence of cognitive impairment, a cross-sectional study in Spain showed that approximately 18.5% of elderly individuals over 65 years of age experience MCI symptoms. In elderly people older than 85 years of age, this percentage can reach up to 50%; this age group is also the one in which elderly individuals are most likely to develop MCI [32]. However, in this study, the average age of the five-guaranteed elderly individuals was 78.14 years, and the prevalence of MCI was as high as 45.7%, approaching 50%. In contrast, a study on the cognitive function of empty nesters with an average age of 68.54 years found that the prevalence of MCI was 38.4% [33]. Although this rate is lower than that in our study, their subjects were also younger, so it is unclear which of these groups exhibits greater cognitive impairment. However, a review article focusing on the cognitive function of older Chinese adults reported that the pooled prevalence of MCI in China was 14.71% [34]. This suggests that the risk of cognitive impairment may be particularly high in five-guaranteed elderly individuals, suggesting that adequate attention and timely intervention are urgently needed.

When comparing the three groups, we found that even though the prevalence rates of depression and anxiety were numerically lower in elderly individuals in the GFII group than those in the SNI group at baseline (depression: 22.6% vs. 46.4%; anxiety: 6.5% vs. 25%), this difference was not significant. Therefore, even though this may reflect slight differences in the emotional state of older adults from different elder care facilities, it did not influence the results of our intervention. A repeated-measures ANOVA, controlling for education level (the only demographic variable that significantly differed at baseline), showed that the main effects of time on the GAD-7 score (a: $p = 0.013$, $\eta^2 = 0.108$; b: $p = 0.019$, $\eta^2 = 0.117$) and s-MoCA score (a: $p = 0.022$, $\eta^2 = 0.094$; b: $p = 0.004$, $\eta^2 = 0.171$) were significant. That is, the anxiety and cognitive function of older adults in all three groups improved significantly after 2 and 4 weeks, and this

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improvement occurred regardless of group. This result is contrary to our hypothesis. We predicted that the SNI and GFII with the graphene cap would lead to varying improvements in the cognitive function and mood levels of the older adults, but this improvement in anxiety and cognitive function was observed even in the control group. Regarding our specific intervention process, for ethical reasons, we provided the older adults participated in the study with a free medical checkup, in which volunteers were available to usher them through various programs, as well as a doctor that they could speak to for free. Even though we provided them with only the most basic indicators, such as measurements of blood pressure and blood glucose, the very process of interacting with people, being cared for, and being valued may have played an important role in improving their mood and cognitive level. Additionally, participation in our study is completely novel compared to their day-to-day routine in the elder care facility, which may have improved cognitive function among five-guarantee elderly individuals and served as a buffer against their prolonged social isolation during the COVID-19 pandemic.

The within-subject results showed that the GFII had a very significant effect on mood and cognitive function in the short term for five-guaranteed elderly individuals. At two weeks, elderly individuals in the GFII group had significantly lower levels of anxiety than those at baseline, while there was a significant improvement in cognitive function. However, while the effect of the intervention on mood indicators may gradually decline over time, the effect on cognitive function remained stable at one month. This may reflect the advantages of the GFII for eliciting cognitive improvements in elderly individuals and, to a certain extent, the ability of the GFII to induce rapid improvements in anxiety symptoms among elderly individuals in the short term. Graphene technology has been effectively used to treat tumors based on the similarity between the emission spectra of the device and the absorption spectra of the living tissue [35]. The present study is the first to apply graphene technology in psychological interventions, and we recommend caution in interpreting the mechanisms underlying these effects; future empirical studies are needed. The probable reason is that graphene far-infrared intervention activates quantum tunneling [36], which leads to the rapid production of some energy, enzymes, and other substances that have an impact on the cognition and mood of the individual.

Additionally, the SNI has also been shown to be a good intervention for cognitive impairment in older adults. Previous research has indicated that demographic factors significantly influence neurodegenerative diseases such as MCI and AD in the elderly [37–39]. Notably, significant risk factors include a lack of formal education, widowhood, divorce or living alone, as well as lifestyle and

quality of life. SNI enriches the leisure activities of the elderly, broadens their horizons, promotes social interaction among them, and further enhances their life satisfaction. This may contribute to the observed improvements in cognitive function associated with the SNI.

There are certainly some limitations of this study. First, the sample size was small, and the attrition rate was not low. However, this was determined by the context and reality of such interventions. The age of five-guaranteed elderly individuals is generally advanced, and many of them were children during the three years of natural disasters in China. They never married for various reasons, such as poverty and their family background, and their parents have long since passed away. This group truly has limited opportunities for happiness, and they have no other source of income except government funding. Over time, the number of people in this group has dwindled. This is another reason it was difficult to recruit a high number of elderly people to participate in the study, even though we conducted whole group sampling in numerous elder care facilities to recruit elderly individuals. The high attrition rate was also determined by their poor health; most of the elderly individuals left the study because they were hospitalized, which was unavoidable considering their advanced age. Another limitation is that self-reported severity of anxiety and depression symptoms may not always be consistent with the assessment of mental health professionals. Similarly, respondents may have been influenced by social desirability bias when reporting their mental health, concealing their real states.

Conclusions

Both interventions have the potential to play a significant role in mitigating the challenges associated with global aging. The GFII has short-term interventions for anxiety in older adults, but long-term effects for cognitive impairment. SNI also had an interventional effect on cognition in older adults. Both interventions are exploratory, and GFII, in particular, is the first to be applied to the field of older adults. The current validated results are exciting and more studies with larger samples and more diverse populations should enter the relevant field in the future. Beyond that, although five-guaranteed elderly individuals may be a subset of the elderly Chinese population in extreme distress, the noninvasive home self-service intervention method of GFII and the social interaction intervention community assistance method of SNI can be promoted to special elderly groups such as empty nesters, elderly who have lost their only child, and even ordinary elderly people.

Abbreviations
GFII   graphene far-infrared radiation intervention
SNI/SNIs   social network intervention/social network interventions

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GFs   graphene films
AD   Alzheimer's disease
FILTS   far-infrared low-temperature sauna
PHQ-9   Patient Health Questionnaire
GAD-7   Generalized Anxiety Disorder Scale
s-MoCA   the short form of the Montreal Cognitive Assessment
MCI   mild cognitive impairment

Data availability
The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
Each participant signed a consent statement. The survey protocol was approved by the ethics review committee of the Institute of Psychology, Chinese Academy of Sciences (Project identification code: H16014).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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