Journal of Geriatric Cardiology | JGC
RESEARCH ARTICLE
J Geriatr Cardiol 2024; 21(7): 733–750

Variations, effectiveness and its associated factors of a nationwide web-based hypertension management training project in China: insights from a government-led campaign for 1.2 million lay health workers

Wei WANG, Hai-Bo ZHANG, Jia-Min LIU, Yan LI, Na TIAN, Lei YAN, Jin-Xiao SONG, Mei-Li LI, Yue PENG, Jing LI✉

National Primary Health Care Hypertension Management Office, National Clinical Research Center for Cardiovascular Diseases, NHC Key Laboratory of Clinical Research for Cardiovascular Medications, Fuwai Hospital, National Center for Cardiovascular Diseases, Chinese Academy of Medical Sciences and Peking Union Medical College, Beijing, China
✉ Correspondence to: jing.li@fwoxford.org
https://doi.org/10.26599/1671-5411.2024.07.010

ABSTRACT

OBJECTIVES To evaluate the effectiveness of a large-scale, web-based, in-service hypertension management training project among lay health workers (LHWs) at primary care health (PHC) settings in China, and to examine the factors contributing to the variations of effectiveness.

METHODS We used data from a web-based national hypertension management training project implemented in 2018, it was designed to facilitate LHWs to learn, understand, and apply the relevant knowledge and skills in hypertension management through providing training courses by use of the web-based platform with unified standards. All LHWs were required to participate in the exams before and after training to acquire scores for the use of evaluating their performance of hypertension management knowledge. We first used descriptive analysis to present the variations of effectiveness in hypertension management knowledge among LHWs by important subgroups. Afterwards, we used multilevel logistic regression to examine the individual and regional factors contributing to the variations and quantify the magnitude of how these factors affected training effectiveness.

RESULTS There were 1,208,610 LHWs who completed training and were certificated. Nationally, the scores of LHWs increased significantly from 62.87 ± 21.14 out of 100 in the pre-test to 88.30 ± 11.31 in the post-test by 25.43 (95% confidence interval [CI]: 25.40-25.47). Training contents involved in antihypertensive medication showed the lowest score (54.36) in the pre-test and soared the most after training, up to 84.22 by 54.94%. Individual factors associated with disparities in the knowledge of hypertension management decreased substantially after training, which included sex, age, education, practice type, professional level, and hierarchy of working institutions. Geographical variations were shown at the provincial level, with the majority of them being explained by factors at the regional level.

CONCLUSIONS Accessible web-based training modality, government efforts, accompanied with experiences derived from the training, could be generalized to other low- and middle-income countries in facilitating the hypertension management capacity of LHWs. Localization and evaluation is warranted on the way to its further application.

Hypertension is the leading cause of mortality and morbidity worldwide and the largest modifiable risk factor of cardiovascular disease (CVD) in China.[1,2] In the health care reform of 2009, the Chinese Central Government launched the National Basic Public Health Service Project (NBPHSP), with hypertension management in primary health care (PHC) settings as one of the national public health priorities.[3] Since then, with published guidelines that provide solid evidence in effective clinical pathways and accessible antihypertensive medication, most hypertensive patients can be treated by lay health workers (LHWs) in PHC settings.[4-6] The capacity of those

institutions and their workforce will largely influence the effectiveness and efficiency of delivering hypertension management services.[4,5] Thus, improving the capacity of hypertension management for LHWs through in-service training is one of the most cost-effective approaches to improve their performance, which can facilitate the patients to control blood pressure (BP) and further reduce the risk of CVD burden.[4-8] The main barriers to this approach include insufficient training opportunities and heterogeneity in training quality.[4,6,9-11]

In recent years, with the rapid development of technology and the popularization of the internet, web-based patterns, which can make up for existing shortcomings of in-service training, have been widely used to facilitate professionals in improving knowledge, behavior, and clinical skills at various healthcare settings, such as clinicians, nurses, and public health practitioners.[11-22] Although previous small-scaled, web-based training strategies among specific healthcare providers were demonstrated to effectively improve professional knowledge in some low- and middle-income countries (LMICs), such as Brazil, India, Egypt, and South America, more evidence with rigorous training strategies and standards evaluation methods are required, particularly in resource-limited areas.[6,9,14,17,20,23-29] However, little existing literature were found regarding the applicability of implementing a large-scale, web-based training project among LHWs in PHC settings, either the performance effectiveness of improving their hypertension management knowledge or that of distributed disparities among subgroups, regions, and contexts in LMICs, especially across diverse venues of a massive country like China, where substantial geographical variations in capacity and expertise exist.

By using data from a government-led, large-scale, web-based in-service training project that provided unified hypertension management standards tailored for LHWs at PHC settings in mainland China, in this study, we aimed to: (1) evaluate the overall effectiveness of web-based hypertension management training project; (2) demonstrate variations in hypertension management knowledge before and after training across individual characteristics, geographical areas, and contextual correlates; and (3) examine the individual and regional factors contributing to the variations and quantify the magnitude of how these factors affected training effectiveness. This study will provide practical evidence for LMICs to initiate large-scale, web-based in-service training that satisfies the needs of LHWs in hypertension management.

METHODS

Data Source

We used the data of a web-based national in-service training project of hypertension management, the PICA Training Project (PICA), which was started in January 2018 and lasted for 1 year. This project was supported by the National Health and Family Planning Commission in China (NHFPC) (now renamed as the National Health Commission, NHC), and designed, implemented, and evaluated by National Center for Cardiovascular Diseases (NCCD).[7] PICA required all LHWs who engaged in hypertension management at PHC settings in mainland China to receive training and obtain certificates, and it aimed to facilitate them to learn, understand and apply the relevant knowledge and skills in hypertension management through providing initial training of the China PHC Diagnosis and Treatment Management Guideline of Hypertension (Guideline) and continuous training of its update version on a web-based platform with unified standards. In PICA, LHWs provided their individual information for authentication and were assigned a unique user ID on the platform. Afterwards, they can access the platform via the browser on computers or an APP on mobile phones at their convenient time to download the Guideline and watch the training video. All LHWs were required to participate in exams before training (pre-test) and after training (post-test) to evaluate their knowledge of hypertension management. Ethical approval was waived because the data were collected for working purposes and only deidentified information was used.

Study Population

The study population included all LHWs from over 326,000 PHC institutions, and 349 municipalities across 31 provinces in mainland China who engaged in hypertension management, finished ini-

tial training, and obtained certificates by the end of 2018. LHWs were defined as healthcare providers who worked in PHC settings, including urban centers (community service centers), urban branches (community service stations), rural centers (township hospitals), and rural branches (village clinics). We excluded those individuals not from PHC institutions (such as national and local health commissions, health administrative institutions, and organizations), with missing values or outliers in key individual characteristics like sex, age, location, and which PHC institution they worked in, and who failed to obtain certificates.

Training Materials, Procedures, and Evaluation

The training materials of PICA included the China PHC Diagnosis and Treatment Management Guideline of Hypertension and the relevant training video. To make it an explicit and practical tool for LWHs, by using simple words, tables, and flowcharts, the Guideline was composed by a writing committee which gathered experts from PHC settings nationwide. According to the contexts involved in the Guideline, a 65-minute video was then recorded and broadcast in advance and hung on the platform to conduct web-based training for LHWs, specifically, it contained three parts: introduction (6 min), hypertension diagnosis, treatment, referral, management, follow-up (22 min) and antihypertensive medication (37 min).

Before training, all LHWs were required to log in to the platform and complete a one-time placement test (pre-test), which reflected their baseline capability of hypertension management. During training, when LHWs watch the training video, they can either suspend, exist, or re-watch the video for many times. After training, LHWs had to take a test shortly after they finished watching the training video to evaluate their capacity of the time (post-test). They had four times opportunities to complete the post-test if they were suspended, existed, failed, or were unsatisfied with the scores they acquired. For each pre-and post-test, the training platform randomly assigned a set of unique question packages with test scores ranging from 0 to 100 which contained 30 question items that covered knowledge points from the Guideline. LHWs who completed the pre-test, watched the training video, and acquired a score of 60 or above out of 100 in the post-test can obtain the training certificates. Detailed description of training and evaluation materials was reported in the supplementary material (see Supplementary Material Part 1 of Table S1).

Outcomes

Outcomes were the scores that LHWs acquired in pre-and post-tests, ranging from 0 to 100. Meanwhile, the scores were also grouped into four grades: ≥ 90 was defined as excellent, 75-89 as good, 60-74 as passed, and < 60 as failed.

Variables

We included both individual and regional characteristics in the analysis. Individual characteristics include: (1) demographics: sex, age; (2) socioeconomic status (SES): education, practice type, professional level, and hierarchy of healthcare institutions. Regional characteristics, which are also called socioeconomic contextual factors, were extracted from National Statistical Data of the Year 2018, which included: (1) location: urban/rural; (2) region: eastern/central/western; (3) provincial per capita gross domestic product (GDP: 10,000 RMB) that represented local economic level; (4) provincial number of LHWs in PHC institutions (per 10,000 persons) that presented local medical resources. Among these, GDP and the number of LHWs were classified into four quartiles.[30] Detailed description of data sources for socioeconomic contextual factors was reported in the supplementary material (see Supplementary Material Part 2 Table S2).

Statistical Analysis

We grouped LHWs by post-test score into excellent (≥ 90) and non-excellent (60-89) ones. We used mean ± SD and count (%) to describe the distribution of continuous and categorical variables. We used χ^2 test to make comparisons of characteristics distribution among nominal categories and logistic regression to test their trends for ordered variables. We performed bootstrapping with an unrestricted random sampling method to generate the estimates of confidence interval (CI) of mean differences between pre-and post-test scores, and the 95% CI was determined based on 2.5th and 97.5th percentile of the bootstrap distribution across 1000 draws.[31]

We conducted multilevel logistic regression to explore the individual factors and regional correlates of LHWs who acquired excellent grades in both pre- and post-tests, respectively. Several models were constructed separately. First, a two-level null model (Model 1) that included fixed and random intercepts was fitted to investigate geographical variations across multiple scales, among which, random intercepts accounted for the clustering of participants (level 1) within provinces (level 2). To quantify the variations of training effectiveness at each level, random effects at the individual level thus were translated into median odds ratio (MOR), which indicated the median of the odds between the province with the highest probability of getting excellent grades and the province with the lowest probability when randomly selected two provinces from all areas. In other words, it reflected the median folds of increased probability of an LHW getting excellent grades in one province with lower odds and moving to another one with higher odds.[32] Further, to explore to what extent those personal and contextual factors explained the geographical variations of LHWs who acquired excellent grades in pre-and post-tests, demographics (Model 2), SES (Model 3), and contextual factors (Model 4) were stepwise entered into the multilevel logistic model and the proportional change in variance (PCV) was calculated for each step. PCV reflected the proportion of variation that can be explained by newly added variables to the model.[33]

In this study, a P value < 0.05 was considered statistically significant and all tests were two-sided. The analysis was performed in SAS 9.4 (SAS Institute Inc., Cary, North Carolina USA). No allowance for multiplicity was made in the analysis.

Role of the Funding Source

The funders of the study have no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding authors have full access to all the data in the study and have final responsibility for the decision to submit for publication.

RESULTS

Characteristics of LHWs

There were 1,810,365 healthcare professionals registered for authentication on the web-based training platform and participated in training. After excluding 397,483 not from PHC institutions, 145,129 with missing/outliers in key variables, 52,655 failed to complete the post-test, and 6,488 failed to pass the post-test, 1,208,610 LHWs (with 99.47% of qualification rate) who passed the post-test and obtained certificates were included in the main analysis (Supplementary Material Figure S1). Among whom, 546,505 (45.22%) were male, the mean age was 44.37 ± 10.39 years old, 689,694 (57.07%) acquired their college degree and above, 652,592 (54.00%) were doctors, 1,034,374 (85.58%) were junior staff. Meanwhile, 179,667 (14.87%) worked in the urban center, 55,534 (4.59%) in the urban branch, 625,910 (51.79%) in the rural center, and 347,499 (28.75%) in the rural branch (Table 1).

Distribution of Training Effectiveness

As shown in Table 2, nationally, the scores of LHWs increased significantly from 62.87 ± 21.14 in the pre-test to 88.30 ± 11.31 in the post-test by 25.43 (95% CI: 25.40-25.47). In the pre-test, LHWs who were females, who aged 60 years and above, who had a college degree and above, who were doctors, and senior staff, who worked in center institutions, as well as urban, eastern, and developed areas showed better performance. As for scores increase, little difference was observed between subgroups. On average, excellent LHWs increased from 67.58 ± 21.68 to 96.35 ± 3.76 (95% CI: 23.83-30.37) while non-excellent ones increased from 56.00 ± 18.27 to 76.57 ± 7.60 (95% CI: 18.95, 22.02). The distribution of pre-and post-test scores by individual and regional factors asas shown in Figure S2 (see Supplementary Material Part 3 Figure S2).

Pre- and post-test scores of LHWs also varied by training contents (Figure 1). Overall, contents involved in antihypertensive medication showed the lowest score (54.36) in the pre-test and soared the most after training, up to 84.22 by 54.94%, followed by comprehensive intervention management, increased from 64.24 to 91.44 by 42.33%. In contrast, contents related to referral and follow-up presented the highest score in both pre-and post-tests. After training, moderate disparities were observed compared with pre-test performance at the individual, regional, and provincial levels.

Table 1 Characteristics of LHWs in PICA, by grade in post-test.

	Total	Excellent LHWs[1]	Non-excellent LHWs[1]	*P*-value
Total	1,208,610 (100.00%)	716,586 (59.29%)	492,024 (40.71%)	< 0.001
Sex				
Male	546,505 (45.22%)	325,413 (45.41%)	221,092 (44.94%)	0.523
Female	662,105 (54.78%)	391,173 (54.59%)	270,932 (55.06%)	
$P_{\text{for difference}}$	0.005	0.005	0.004	
Age, yrs	44.37 ± 10.39	44.93 ± 9.98	43.57 ± 10.91	0.132
Age groups, yrs				
18-29	110,863 (9.17%)	50,577 (7.06%)	60,286 (12.25%)	0.061
30-44	517,041 (42.78%)	306,579 (42.78%)	210,462 (42.77%)	
45-59	499,658 (41.34%)	312,479 (43.61%)	187,179 (38.04%)	
60 and above	81,048 (6.71%)	46,951 (6.55%)	34,097 (6.93%)	
$P_{\text{for trend}}$	0.004	0.005	0.005	
Education				
Below college	518,916 (42.93%)	308,929 (43.11%)	209,987 (42.68%)	0.139
College and above	689,694 (57.07%)	407,657 (56.89%)	282,037 (57.32%)	
$P_{\text{for difference}}$	0.004	0.005	0.004	
Practice type				
Doctors	652,592 (54.00%)	412,996 (57.63%)	239,596 (48.70%)	0.018
Nurses	217,968 (18.03%)	125,237 (17.48%)	92,731 (18.85%)	
Others[2]	338,050 (27.97%)	178,353 (24.89%)	159,697 (32.46%)	
$P_{\text{for difference}}$	< 0.001	< 0.001	< 0.001	
Professional level				
Junior	1,034,374 (85.58%)	599,254 (83.63%)	435,120 (88.43%)	0.012
Intermediate	140,493 (11.62%)	93,789 (13.09%)	46,704 (9.49%)	
Senior	33,743 (2.79%)	23,543 (3.29%)	10,200 (2.07%)	
$P_{\text{for trend}}$	< 0.001	< 0.001	< 0.001	
Hierarchy of healthcare institutions				
Urban center	179,667 (14.87%)	108,625 (15.16%)	71,042 (14.44%)	0.046
Urban branch	55,534 (4.59%)	33,254 (4.64%)	22,280 (4.53%)	
Rural center	625,910 (51.79%)	368,875 (51.48%)	257,035 (52.24%)	
Rural branch	347,499 (28.75%)	205,832 (28.72%)	141,667 (28.79%)	
$P_{\text{for difference}}$	< 0.001	< 0.001	< 0.001	
Location				
Urban	235,201 (19.46%)	141,879 (19.80%)	93,322 (18.97%)	0.042
Rural	973,409 (80.54%)	574,707 (80.20%)	398,702 (81.03%)	
$P_{\text{for difference}}$	< 0.001	< 0.001	< 0.001	

Continued

	Total	Excellent LHWs[1]	Non-excellent LHWs[1]	*P*-value
Region[3]				
Eastern	459,102 (37.99%)	285,924 (39.90%)	173,178 (35.20%)	0.017
Central	393,794 (32.58%)	225,471 (31.46%)	168,323 (34.21%)	
Western	355,714 (29.43%)	205,191 (28.63%)	150,523 (30.59%)	
$P_{\text{for difference}}$	0.007	0.005	0.008	
GDP (10,000 RMB)				
Q1 (< 4.49)	252,262 (20.87%)	143,463 (20.02%)	108,799 (22.11%)	< 0.001
Q2 (4.49-5.16)	228,016 (18.87%)	106,783 (14.90%)	121,233 (24.64%)	
Q3 (5.17-7.11)	431,332 (35.69%)	274,614 (38.32%)	156,718 (31.85%)	
Q4 (> 7.11)	297,000 (24.57%)	191,726 (26.76%)	105,274 (21.40%)	
$P_{\text{for trend}}$	0.009	0.008	0.009	
Number of LHWs (per 10 000 persons)[4]				
Q1 (< 25.18)	189,362 (15.67%)	111,297 (15.53%)	78,065 (15.87%)	< 0.001
Q2 (25.18-28.56)	292,365 (24.19%)	186,794 (26.07%)	105,571 (21.46%)	
Q3 (28.57-30.53)	409,752 (33.90%)	227,548 (31.75%)	182,204 (37.03%)	
Q4 (> 30.53)	317,131 (26.24%)	190,947 (26.65%)	126,184 (25.65%)	
$P_{\text{for trend}}$	0.007	0.006	0.007	

Data are presented as mean ± SD or *n* (%). [1]Excellent LHWs referred to those who acquired excellent scores (≥ 90) in the post-test and were certificated in PICA, non-excellent LHWs referred to those who acquired non-excellent scores (60-89) in the post-test and were certificated in PICA. [2]Other practice types included pharmacists, technicians, and other healthcare-related personnel.[3]Region: Western: Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang; Central: Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan; Eastern: Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan. [4] Number of LHWs: Provincial number of LHWs in primary healthcare institutions (per 10 000 persons). LHWs: lay health workers; GDP: per capita gross domestic product; Q1: 25th quartile; Q2: 50th quartile; Q3: 75th quartile; Q4: 100th quartile.

The distribution of pre- and post-test grades of LHWs is presented in Figure 2. In total, the percentage of excellent grades increased from 16.22% in the pre-test to 58.53% in the post-test. In the post-test, LHWs who were aged 45-59 years (62.54%), being doctors (63.29%), senior staff (69.77%), who worked in worked in the urban center (60.46%), as well as urban (60.32%) and eastern areas (62.28%) obtained a higher percentage of excellent grade compared with their counterparts. As for provincial variations, Beijing (80.14%), Shanghai (77.64%), and Hubei (74.88%) were the top three provinces with the highest percentage of excellent grades in the post-test.

Associated Factors of Training Effectiveness

Multilevel modeling results demonstrated that socioeconomic contextual factors, including location, region, provincial GDP, and number of LHWs, explained the majority of the geographical variations among LHWs who acquired excellent grades compared with individual factors, for PCV increased from 4.16% in Model 3 to 8.09% in Model 4 in pre-test and from 9.41% to 18.28% in post-test below the provincial scale. Meanwhile, the result of MOR for 4 separate models was all greater than 1, which also indicated significant geographical variations and helped to explain regional differences in getting excellent grades (see Supplementary Material Part 3 Table S3, Table S4).

By using the estimation from Model 4, the associations between factors and the probability of getting excellent grades among LHWs are presented in Figure 3. In both pre-and post-test, LHWs who were men (0.88, 95% CI: 0.87-0.89 *vs.* 0.94, 95% CI:

Table 2 Distribution of pre-and post-test scores among LHWs in PICA, by grade in post-test.

	Total			Excellent LHWs[1]			Non-excellent LHWs[1]		
	Pre-test	Post-test	Differences (95% CI)	Pre-test	Post-test	Differences (95% CI)	Pre-test	Post-test	Differences (95% CI)
Total	62.87 ± 21.14	88.30 ± 11.31	25.43 (25.40-25.47)	67.58 ± 21.68	96.35 ± 3.76	27.10 (23.83-30.37)	56.00 ± 18.27	76.57 ± 7.60	20.56 (18.95-22.02)
Sex									
Male	62.40 ± 21.01	88.45 ± 11.31	25.43 (23.39-27.47)	66.78 ± 21.60	96.45 ± 3.76	28.75 (25.30-30.20)	55.94 ± 18.28	76.66 ± 7.91	20.51 (19.04-21.97)
Female	63.25 ± 21.25	88.18 ± 11.31	25.36 (23.44-27.28)	68.24 ± 21.73	96.26 ± 3.76	27.01 (25.33-30.89)	56.05 ± 18.26	76.50 ± 7.82	20.57 (19.14-21.85)
Age groups (years)									
18-29	58.86 ± 21.66	84.48 ± 12.13	25.39 (23.59-27.20)	65.94 ± 23.29	95.65 ± 3.80	26.91 (23.27-30.55)	52.91 ± 18.18	75.11 ± 8.11	20.71 (19.03-22.39)
30-44	62.62 ± 20.49	88.30 ± 11.27	25.43 (23.71-27.14)	67.07 ± 21.07	96.32 ± 3.77	26.99 (23.26-30.73)	56.14 ± 17.71	76.62 ± 7.80	20.68 (19.10-22.27)
45-59	63.57 ± 21.12	89.19 ± 11.00	25.44 (23.82-27.07)	67.74 ± 21.56	96.52 ± 3.73	27.16 (23.28-30.85)	56.62 ± 18.37	76.97 ± 7.80	20.65 (19.13-22.17)
60 and above	65.56 ± 23.73	87.99 ± 11.25	25.17 (22.87-27.47)	71.62 ± 24.03	96.19 ± 3.75	26.13 (23.26-29.79)	57.22 ± 20.57	76.70 ± 7.84	20.54 (18.95-22.13)
Education									
Below college	62.58 ± 22.08	88.34 ± 11.35	25.52 (22.99-27.45)	67.26 ± 22.77	96.33 ± 3.75	27.08 (23.27-30.93)	55.69 ± 19.03	76.59 ± 8.11	20.57 (19.04-22.11)
College and above	63.08 ± 20.41	88.27 ± 11.28	25.22 (23.08-27.36)	67.82 ± 20.82	96.37 ± 3.77	27.15 (23.30-31.00)	56.24 ± 17.68	76.56 ± 7.67	20.55 (19.07-22.04)
Practice type									
Doctors	64.08 ± 20.29	89.44 ± 10.84	25.23 (23.16-27.29)	67.99 ± 20.58	96.56 ± 3.74	27.57 (26.52-28.62)	57.33 ± 17.86	77.17 ± 7.63	20.50 (19.03-21.98)
Nurses	62.62 ± 22.18	87.66 ± 11.36	25.21 (23.22-27.21)	68.13 ± 22.98	96.05 ± 3.75	27.04 (26.59-28.89)	55.18 ± 18.62	76.33 ± 7.79	20.55 (19.09-22.00)
Others[2]	60.68 ± 21.88	86.50 ± 11.89	25.65 (23.30-27.21)	66.23 ± 23.13	96.07 ± 3.79	27.77 (26.20-29.35)	54.49 ± 18.52	75.81 ± 8.17	20.60 (19.14-22.05)
Professional level									
Junior	62.12 ± 21.43	87.93 ± 11.41	25.63 (23.16-27.29)	66.93 ± 22.16	96.27 ± 3.77	28.92 (27.47-30.36)	55.50 ± 18.41	76.45 ± 7.91	20.62 (19.19-22.04)
Intermediate	66.99 ± 18.86	90.33 ± 10.47	25.18 (23.12-27.23)	70.64 ± 18.87	96.72 ± 3.70	26.35 (25.78-30.92)	59.67 ± 16.57	77.48 ± 7.43	20.46 (18.59-22.33)
Senior	68.45 ± 18.44	91.10 ± 10.17	25.04 (22.76-27.33)	71.88 ± 18.04	96.89 ± 3.66	25.09 (24.41-31.18)	60.55 ± 16.88	77.73 ± 7.43	20.29 (17.96-22.61)
Hierarchy of healthcare institutions									
Urban center	64.65 ± 20.30	88.63 ± 11.19	24.99 (22.71-27.27)	69.66 ± 20.27	96.45 ± 3.75	27.05 (24.44-30.86)	56.99 ± 17.80	76.66 ± 7.67	20.26 (17.98-22.53)
Urban branch	63.89 ± 20.16	88.57 ± 11.22	24.97 (22.75-27.20)	68.46 ± 20.59	96.46 ± 3.77	27.09 (24.68-30.70)	57.07 ± 17.39	76.79 ± 7.82	20.23 (18.00-22.47)
Rural center	62.90 ± 21.48	88.12 ± 11.36	24.99 (22.81-27.16)	67.86 ± 22.00	96.26 ± 3.76	27.77 (24.90-30.64)	55.78 ± 18.54	76.45 ± 7.92	20.25 (18.06-22.44)
Rural branch	61.72 ± 21.03	88.40 ± 11.29	25.66 (22.83-27.29)	65.84 ± 21.89	96.44 ± 3.77	28.05 (24.86-31.25)	55.75 ± 18.12	76.72 ± 7.85	20.78 (18.12-22.44)

Continued

	Total			Excellent LHWs[1]			Non-excellent LHWs[1]		
	Pre-test	Post-test	Differences (95% CI)	Pre-test	Post-test	Differences (95% CI)	Pre-test	Post-test	Differences (95% CI)
Location									
Urban	64.47 ± 20.27	88.61 ± 11.20	24.14 (24.07-24.21)	69.38 ± 20.35	96.45 ± 3.76	25.22 (23.07-27.36)	57.01 ± 17.71	76.70 ± 7.70	19.69 (19.59-19.78)
Rural	62.48 ± 21.33	88.22 ± 11.34	25.44 (23.37-27.51)	67.13 ± 21.98	96.32 ± 3.76	27.34 (25.84-29.84)	55.77 ± 18.39	76.54 ± 7.90	20.73 (19.16-21.30)
Region[3]									
Eastern	64.97 ± 20.47	89.08 ± 11.09	24.66 (23.17-26.16)	69.62 ± 20.66	96.55 ± 3.72	25.38 (22.87-27.90)	57.29 ± 17.63	76.73 ± 7.65	19.97 (18.84-21.10)
Central	62.41 ± 21.27	87.93 ± 11.37	24.88 (23.39-26.36)	67.30 ± 21.95	96.39 ± 3.77	27.49 (24.73-30.25)	55.86 ± 18.38	76.59 ± 7.70	20.36 (18.98-21.34)
Western	60.66 ± 21.60	87.70 ± 11.47	25.51 (23.16-27.46)	65.04 ± 22.48	96.02 ± 3.79	28.64 (26.40-30.89)	54.68 ± 18.77	76.36 ± 8.26	20.66 (18.88-22.05)
GDP (10,000 RMB)									
Q1 (< 4.49)	60.90 ± 21.14	87.63 ± 11.40	25.33 (22.85-27.41)	65.24 ± 22.09	96.09 ± 3.80	28.31 (24.88-31.73)	55.17 ± 18.30	76.48 ± 7.97	20.62 (18.17-22.48)
Q2 (4.49-5.16)	60.35 ± 20.72	85.34 ± 11.81	25.32 (22.89-27.36)	66.68 ± 21.67	96.01 ± 3.85	27.39 (24.07-30.72)	54.78 ± 18.09	75.93 ± 7.78	20.46 (18.22-22.49)
Q3 (5.17-7.11)	63.57 ± 21.44	89.36 ± 11.06	25.45 (22.94-27.36)	67.60 ± 21.97	96.54 ± 3.72	27.44 (24.23-30.65)	56.51 ± 18.47	76.79 ± 8.00	20.35 (18.26-22.45)
Q4 (>7.11)	65.44 ± 20.66	89.59 ± 10.73	25.31 (22.91-27.31)	69.80 ± 20.73	96.46 ± 3.72	26.31 (23.09-29.53)	57.51 ± 18.00	77.08 ± 7.58	20.33 (18.25-22.40)
Number of LHWs (per 10,000 persons)[4]									
Q1 (< 25.18)	62.90 ± 20.92	88.23 ± 11.29	25.12 (22.96-27.28)	67.69 ± 21.37	96.37 ± 3.76	27.03 (24.22-30.45)	56.07 ± 18.20	76.61 ± 7.69	20.53 (18.29-22.37)
Q2 (25.18-28.56)	63.64 ± 21.58	89.36 ± 10.87	25.34 (23.01-27.27)	67.71 ± 21.98	96.36 ± 3.73	27.05 (24.33-30.38)	56.45 ± 18.82	76.98 ± 7.91	20.44 (18.34-22.35)
Q3 (28.57-30.53)	62.42 ± 20.71	87.45 ± 11.42	25.44 (23.04-27.24)	67.40 ± 21.42	96.20 ± 3.80	27.18 (24.44-30.32)	56.20 ± 17.93	76.52 ± 7.76	20.44 (18.37-22.31)
Q4 (>30.53)	62.71 ± 21.40	88.45 ± 11.49	25.46 (23.08-27.23)	67.60 ± 21.88	96.50 ± 3.74	27.41 (24.54-30.27)	55.30 ± 18.32	76.28 ± 8.04	20.56 (18.41-22.31)

Data are presented as mean ± SD. [1]Excellent LHWs referred to those who acquired excellent scores (≥ 90) in the post-test and were certificated in PICA, non-excellent LHWs referred to those who acquired non-excellent scores (60-89) in the post-test and were certificated in PICA. [2]Other practice types included pharmacists, technicians, and other healthcare-related personnel. [3]Region: Western: Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang; Central: Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan; Eastern: Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan. [4] Number of LHWs: Provincial number of LHWs in primary healthcare institutions (per 10 000 persons). LHWs: lay health workers; GDP: per capita gross domestic product; Q1: 25th quartile; Q2: 50th quartile; Q3: 75th quartile; Q4: 100th quartile.

(A) Individual factors

Pre–test

	Blood pressure measurement	Diagnosis and evaluation	Treatment principles and blood pressure control goals	Lifestyle intervention	Medication	Comprehensive intervention management	Referral and follow–up
Total	64.72	73.03	70.17	68.55	54.36	64.24	76.59
Male	64.37	72.45	70	67.37	53.86	64.51	76.97
Female	65.01	73.51	70.32	69.51	54.77	64.02	76.28
18–29	62.63	68.04	67.61	65.03	50.51	58.18	67.93
30–44	64.32	72.86	70.69	68.42	53.65	62.88	76.74
45–59	65.09	73.98	70.12	69.03	55.17	65.99	78.21
60 and above	67.72	75.12	70.73	71.36	59.2	70.7	78.09
Below college	64.82	72.86	69.32	67.7	54.41	64.96	76.48
College and above	64.64	73.16	70.82	69.18	54.32	63.71	76.67
Doctors	65.1	74.32	71.35	69.4	55.49	66.16	79.64
Nurses	65.29	72.66	70.41	68.77	54.15	62.5	73.6
Others	63.58	70.78	67.76	66.78	52.3	61.67	72.75
Junior	64.37	72.34	69.52	67.63	53.63	63.47	75.62
Intermediate	66.72	76.96	73.94	73.7	58.27	68.4	82.08
Senior	67.11	77.86	74.65	75.04	60.38	70.71	83.59
Urban center	65.38	74.05	71.76	72.41	56.01	65.48	77.69
Urban branch	65.42	73.89	71.34	70.86	55.22	65.12	78.42
Rural center	64.79	72.97	70.2	68.16	54.51	63.88	75.83
Rural branch	64.13	72.49	69.13	66.85	53.09	64.1	77.1

Scores 100 90 80 70 60 50 40

Post–test

	Blood pressure measurement	Diagnosis and evaluation	Treatment principles and blood pressure control goals	Lifestyle intervention	Medication	Comprehensive intervention management	Referral and follow–up
Total	88.01	92.3	89.46	92.78	84.22	91.44	93.15
Male	88.09	92.49	89.68	92.62	84.36	91.8	93.5
Female	87.94	92.15	89.27	92.91	84.11	91.14	92.86
18–29	85.13	89.36	86.26	90.75	79.47	86.9	89.25
30–44	88.08	92.21	89.55	92.87	84.2	91.25	93.25
45–59	88.66	93.07	90.15	93.2	85.37	92.53	93.93
60 and above	87.34	92.2	88.92	92.43	83.78	92.13	93.21
Below college	87.86	92.56	89.42	92.63	84.2	91.98	93.4
College and above	88.13	92.11	89.48	92.9	84.24	91.03	92.96
Doctors	88.89	93.08	90.42	93.31	85.74	92.6	94.23
Nurses	87.75	91.87	88.93	92.71	83.29	90.71	92.51
Others	86.45	91.08	87.93	91.82	81.9	89.65	91.51
Junior	87.66	92.1	89.14	92.52	83.73	91.18	92.89
Intermediate	89.95	93.43	91.22	94.24	86.95	92.82	94.62
Senior	90.71	93.98	91.9	94.62	88.02	93.47	95.02
Urban center	88.42	92.12	89.81	93.56	84.77	91.03	93.06
Urban branch	88.3	92.3	89.89	93.19	84.66	91.2	93.19
Rural center	87.92	92.26	89.27	92.64	83.95	91.35	93.06
Rural branch	87.91	92.48	89.54	92.57	84.36	91.85	93.35

Scores 100 90 80 70 60 50 40

Change, %

	Blood pressure measurement	Diagnosis and evaluation	Treatment principles and blood pressure control goals	Lifestyle intervention	Medication	Comprehensive intervention management	Referral and follow–up
Total	35.99	26.39	27.48	35.35	54.94	42.33	21.62
Male	36.86	27.66	28.1	37.47	56.62	42.31	21.47
Female	35.28	25.36	26.96	33.67	53.58	42.35	21.74
18–29	35.91	31.34	27.59	39.55	57.33	49.38	31.38
30–44	36.94	26.55	26.68	35.74	56.94	45.12	21.52
45–59	36.22	25.79	28.57	35.03	54.73	40.21	20.1
60 and above	28.98	22.74	25.71	29.53	41.52	30.3	19.37
Below college	35.53	27.04	28.99	36.81	54.74	41.59	22.13
College and above	36.34	25.9	26.36	34.29	55.1	42.89	21.24
Doctors	36.53	25.24	26.74	34.46	54.5	39.96	18.31
Nurses	34.4	26.43	26.3	34.8	53.81	45.14	25.69
Others	35.97	28.68	29.77	37.5	56.6	45.37	25.79
Junior	36.19	27.31	28.22	36.8	56.13	43.67	22.84
Intermediate	34.82	21.4	23.37	27.87	49.22	35.71	15.29
Senior	35.16	20.69	23.12	26.09	45.77	32.19	13.67
Urban center	35.24	24.41	25.15	29.22	51.34	39	19.8
Urban branch	34.97	24.92	26.01	31.5	53.3	40.04	18.83
Rural center	35.7	26.44	27.17	35.9	54.01	42.99	22.71
Rural branch	37.09	27.58	29.53	38.48	58.91	43.28	21.08

Change, % 70 60 50 40 30 20 10

(B) Regional factors

Pre−test

	Blood pressure measurement	Diagnosis and evaluation	Treatment principles and blood pressure control goals	Lifestyle intervention	Medication	Comprehensive intervention management	Referral and follow−up
Urban	35.18	24.53	25.35	29.75	51.8	39.25	19.57
Rural	36.19	26.84	28	36.81	55.73	43.09	22.13
Eastern	34.44	23.89	24.83	31.08	51.39	37.64	18.45
Central	35.67	26.79	28.02	36.92	54.66	41.45	22.41
Western	38.42	29.3	30.48	39.54	60.25	49.99	25.09
GDP_Q1	37.87	28.95	29.36	40.52	59.02	48.03	24.28
GDP_Q2	35.62	28.13	29.69	36.35	54.04	42.06	25.59
GDP_Q3	35.89	26.09	27.67	34.71	55.98	42.34	20.57
GDP_Q4	34.87	23.54	24.14	31.48	50.95	38.08	18.14
LHWs_Q1	36.19	26.06	26.87	36.23	54.68	41.05	21.64
LHWs_Q2	36.18	26.25	26.53	35.68	55.07	43.55	20.93
LHWs_Q3	35.54	26.22	27.52	35.69	53.92	41.29	22.02
LHWs_Q4	36.27	26.93	28.67	34.12	56.31	43.3	21.73

Scores 100 90 80 70 60 50 40

Post−test

	Blood pressure measurement	Diagnosis and evaluation	Treatment principles and blood pressure control goals	Lifestyle intervention	Medication	Comprehensive intervention management	Referral and follow−up
Urban	88.39	92.16	89.83	93.47	84.74	91.07	93.09
Rural	87.92	92.34	89.37	92.61	84.1	91.53	93.16
Eastern	88.82	92.59	90.09	93.33	85.38	91.88	93.54
Central	87.74	91.81	89.24	92.59	83.88	90.9	92.46
Western	87.28	92.48	88.87	92.28	83.11	91.46	93.42
GDP_Q1	87.39	92.06	88.84	92.09	83.2	91.23	93.09
GDP_Q2	85.44	89.43	86.92	91.35	80.87	87.77	89.66
GDP_Q3	88.9	93.29	90.41	93.38	85.45	92.75	94.29
GDP_Q4	89.08	93.27	90.55	93.64	85.87	92.52	94.36
LHWs_Q1	87.98	92.1	89.32	92.64	84.22	91.19	93.14
LHWs_Q2	88.74	93.46	90.32	93.38	85.38	92.87	94.53
LHWs_Q3	87.3	91.43	88.76	92.24	83.3	90.39	92.15
LHWs_Q4	88.24	92.49	89.63	93.03	84.35	91.61	93.21

Scores 100 90 80 70 60 50 40

Change, %

	Blood pressure measurement	Diagnosis and evaluation	Treatment principles and blood pressure control goals	Lifestyle intervention	Medication	Comprehensive intervention management	Referral and follow−up
Urban	35.18	24.53	25.35	29.75	51.8	39.25	19.57
Rural	36.19	26.84	28	36.81	55.73	43.09	22.13
Eastern	34.44	23.89	24.83	31.08	51.39	37.64	18.45
Central	35.67	26.79	28.02	36.92	54.66	41.45	22.41
Western	38.42	29.3	30.48	39.54	60.25	49.99	25.09
GDP_Q1	37.87	28.95	29.36	40.52	59.02	48.03	24.28
GDP_Q2	35.62	28.13	29.69	36.35	54.04	42.06	25.59
GDP_Q3	35.89	26.09	27.67	34.71	55.98	42.34	20.57
GDP_Q4	34.87	23.54	24.14	31.48	50.95	38.08	18.14
LHWs_Q1	36.19	26.06	26.87	36.23	54.68	41.05	21.64
LHWs_Q2	36.18	26.25	26.53	35.68	55.07	43.55	20.93
LHWs_Q3	35.54	26.22	27.52	35.69	53.92	41.29	22.02
LHWs_Q4	36.27	26.93	28.67	34.12	56.31	43.3	21.73

Change, % 70 60 50 40 30 20 10

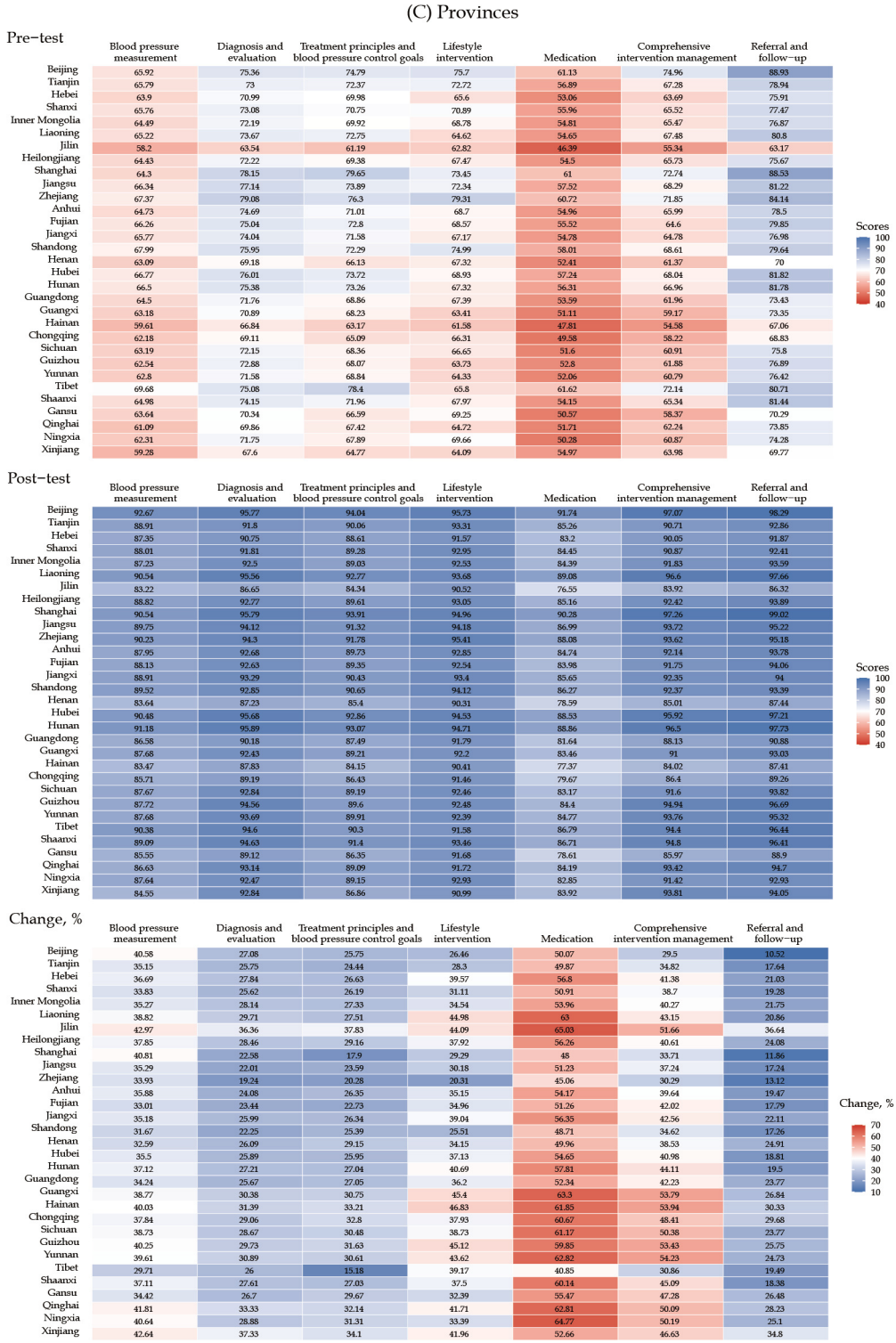

Figure 1 Distribution of pre-and post-test scores among LHWs in PICA, by training contents. (A): individual factors; (B): regional factors; (C): provinces. [1]Other practice types included pharmacists, technicians, and other healthcare-related personnel. [2]Region: Western: Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang; Central: Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan; Eastern: Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan. [3] Number of LHWs: Provincial number of LHWs in primary healthcare institutions (per 10,000 persons). LHWs: lay health workers; GDP: per capita gross domestic product; Q1: 25th quartile; Q2: 50th quartile; Q3: 75th quartile; Q4: 100th quartile.

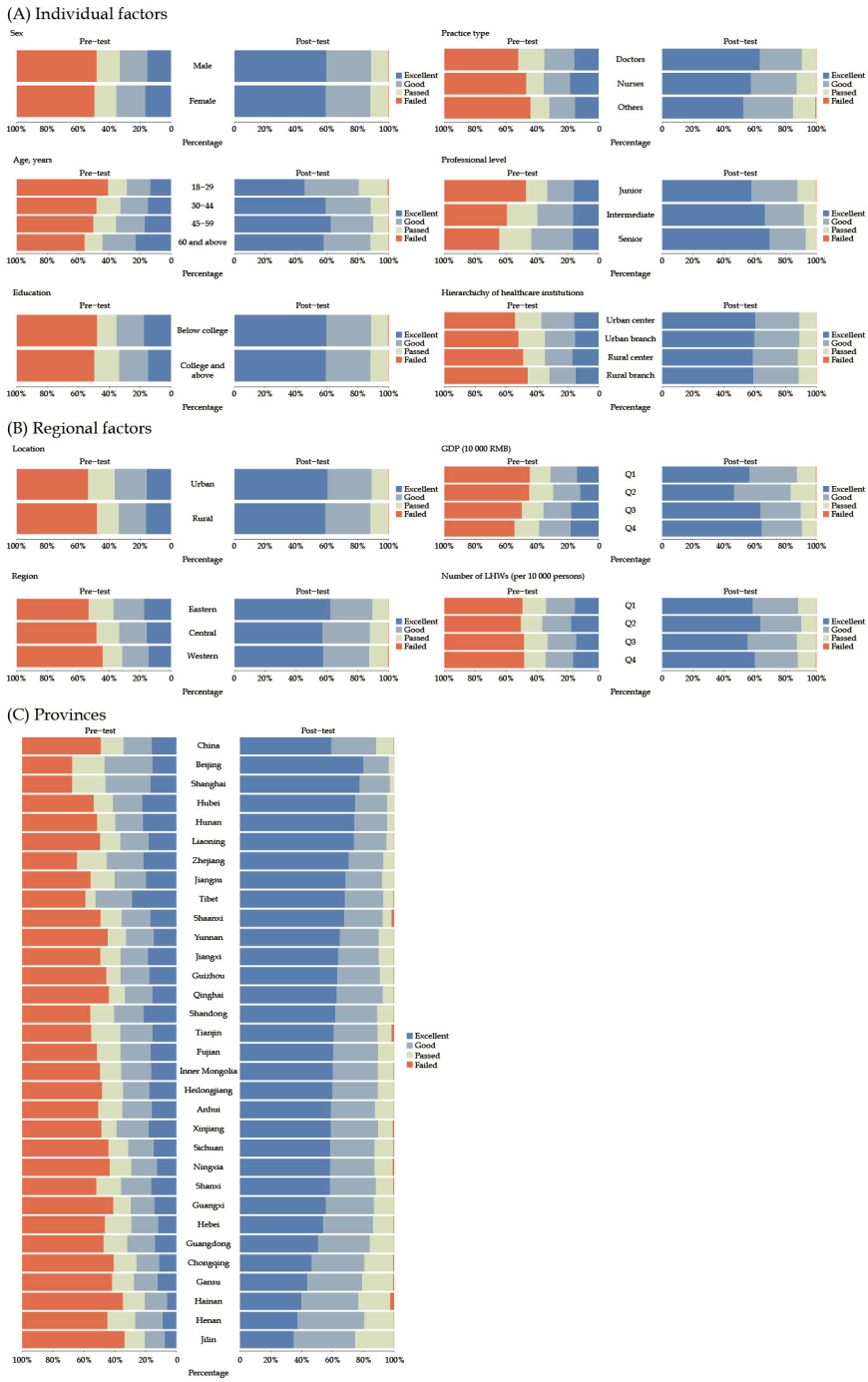

Figure 2 Distribution of pre-and post-test grades among LHWs in PICA. (A): Individual factors; (B): regional factors; (C): provinces. [1]Other practice types included pharmacists, technicians, and other healthcare-related personnel. [2]Region: Western: Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang; Central: Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan; Eastern: Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan. [3]Number of LHWs: Provincial number of LHWs in primary healthcare institutions (per 10 000 persons). LHWs: lay health workers; GDP: per capita gross domestic product; Q1: 25th quartile; Q2: 50th quartile; Q3: 75th quartile; Q4: 100th quartile.

0.93-0.95), who did not have a college degree (0.84, 95% CI: 0.83-0.85 *vs.* 0.97, 95% CI: 0.96-0.98), who worked in branch institutions (0.81, 95% CI: 0.80-0.82 *vs.* 0.96, 95% CI: 0.95-0.97) and rural areas (0.94, 95% CI: 0.93-0.96 *vs.* 0.94, 95% CI: 0.98, 0.97-0.99) had a lower probability of acquiring excellent grade

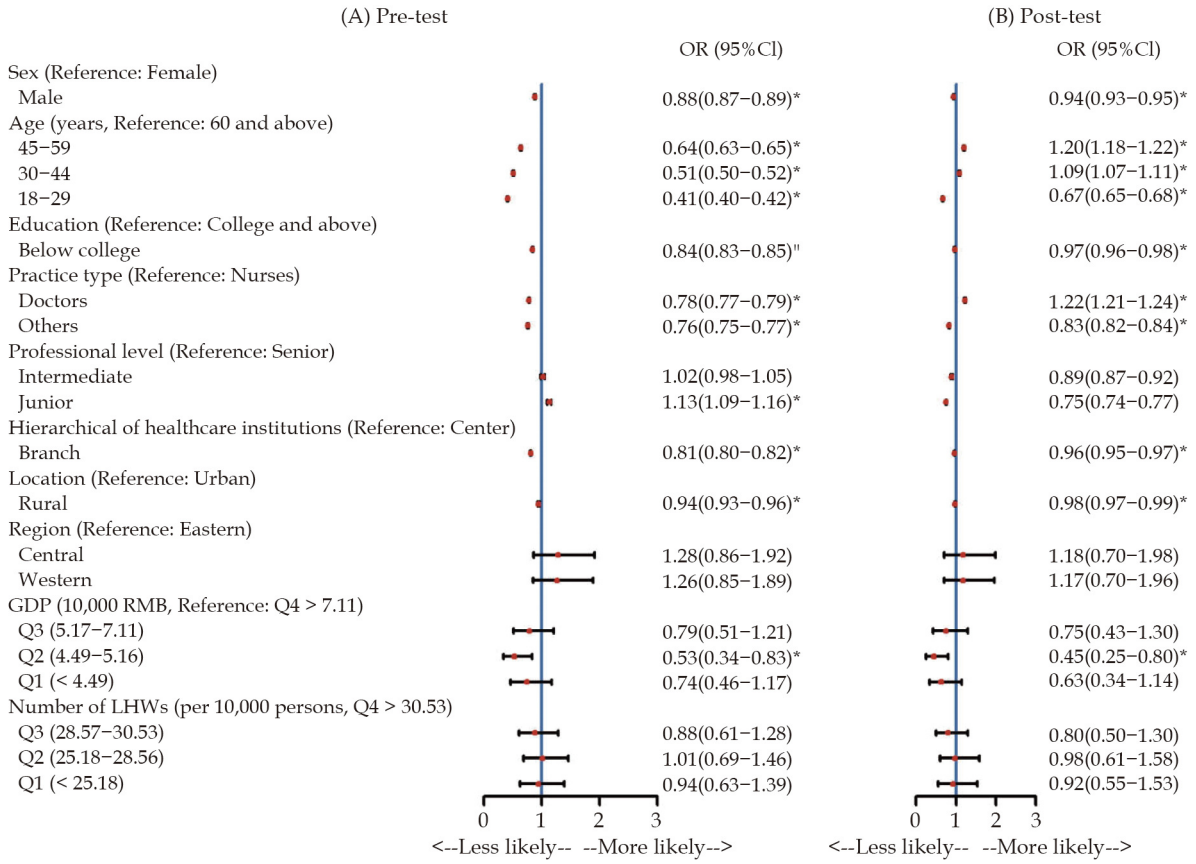

Figure 3 Associated factors of LHWs who acquired excellent grades in pre-and post-tests of PICA. (A): Pre-test; (B): post-test. [1]*P < 0.05. [2]Other practice types included pharmacists, technicians, and other healthcare-related personnel. [3]Region: Western: Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang; Central: Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan; Eastern: Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan. [4]Number of LHWs: Provincial number of LHWs in primary healthcare institutions (per 10,000 persons). LHWs: lay health workers; GDP: per capita gross domestic product; Q1: 25th quartile; Q2: 50th quartile; Q3: 75th quartile; Q4: 100th quartile; OR: odds ratio; CI: confidence interval.

compared with their counterparts, and the disparities of those odds between each subgroup were substantially narrowed by PICA training. Apart from this, the absolute probability of obtaining excellent grades existed differentially in the direction across subpopulations in pre-and post-tests. As for age, LHWs who aged 60 and above had the highest odds of excellent in the pre-test while those aged 30-59 years had higher odds in the post-test. Doctors showed higher odds of excellence in the post-test than nurses although nurses had higher odds in the pre-test. And, senior staff had the highest odds of excellent in the post-test while junior ones in the pre-test.

Discussion

By using data from a national training project that was implemented within 1-year and covering 1.2 million LHWs, we illustrated the substantial effectiveness of a web-based strategy to provide large-scale, wide-coverage in-service training for LHWs to enhance their knowledge of hypertension management in China, and these effects were consistent regardless of geographical areas, economical levels and medical resources. Meanwhile, the hypertension management knowledge variations across sex, age, education attainment, practice type, professional level, and healthcare institution were considerably reduced by training.

Substantial Training Effectiveness Existed Regardless of Subgroups, Regions, And Contents

LHWs in China often do not have adequate training and qualifications in the capacity of hypertension management, and this was largely ameliorated

by PICA implementation. Variations of pre-test performance were observed among LHWs with different individual characteristics, with similar increases in training scores across subgroups. LHWs who had shorter practice experiences, with lower academic degrees, and worked in rural areas and lower-level healthcare units acquired lower pre-test scores. It was observed in the distribution of acquiring excellent grades likewise, and consistent with existing findings.[9,13] After training, those LHWs with higher post-test scores were found to obtain higher increases compared with those with lower scores, and it can be partially explained by adequate accessibility of being trained among LHWs who already have better performance. Previous literature suggested that healthcare providers from LMICs acquired more or at least identical improvement after in-service training than that from high-income countries once they have equal opportunities to receive training.[9,10,14,34] Thus, accessibility and feasibility, including the equal opportunity of being trained, affordable approaches should be encouraged in organizing in-service training for LHWs from various backgrounds.

Significant geographical variations of professional capacity among LHWs existed, with similar improvement across provinces. LHWs from developed regions located in eastern China, like Beijing, Shanghai, and Zhejiang, tended to have higher levels of hypertension management knowledge, others from less developed provinces showed poor condition. Such disparities could be partially associated with the quantity and quality of licensure and education of LHWs. Since health care reform in 2009, although the number of LHWs has been increasing, there was a two-times difference across provinces in the number of licensed doctors in urban areas, while a 16-times difference for village doctors in rural settings.[5] Similarly, a previous national survey revealed that the proportion of licensed doctors was much lower in western regions compared with eastern ones, and a higher rate of receiving no continuing training sessions was also observed in western regions.[5] Unified web-based approach in PICA can equally provide training sessions to regions with different resources, which facilitated those inferior regions with identical improvement in training performance considerably. Among these, regions with lower baseline scores were inclined to acquire a higher percentage of increase upon completing the training, although not exceeding their counterparts in the post-test. Therefore, we suggested to produce flexible training sessions in the consideration of local characteristics on the basis of a standardized framework, for areas with poor performance should be devoted to filling in the gaps and acquiring further improvement.[4,5,35]

Unequal performance was found in different training contents of PICA. Antihypertensive medication is the core component of hypertension management, it was the most complicated session with the poorest performance and was improved most after training. These findings were consistent with previous studies conducted in hospital settings at home and overseas, and it was also an extended application in PHC settings.[10,36,37] To be specific, it was reported that, for one reason, LHWs were too busy to attend training for further acquiring knowledge of hypertension management, especially for antihypertensive medication; for another, some of the training failed to meet their need due to short duration, poor contents, insufficient practice, and unqualified trainers.[6,9,10] According to several nationwide surveys, hypertension was largely undertreated, with prescribing behavior as one of the most influential factors. A low level of knowledge in medication presented in the pre-test suggested that other than medication supply defects, LHWs' knowledge of proper antihypertension medication should be addressed, which might partly explain the poor BP management in PHC settings.[8,37] In PICA, the training project spent 60% of training time on antihypertensive medication, using explicit, practical, and standardized contents that were easier to be understood by LHWs. We observed substantial improvement with reduced variations across individual, regional, and provincial levels. Continuity in facilitating the ability to medication should be the priority to increase the hypertension management capacity for LHWs effectively. Apart from medication, referral, and follow-up, as well as treatment principles and BP control goals were contents that LHWs both got higher scores before and after training, the reasons might be related to the significant effectiveness of several government-led public health campaigns to promote hypertension prevention, control, treat-

ment, management at PHC settings, such as NEPHSP since 2009.[3] Additionally, lifestyle intervention and comprehensive intervention management were sessions that need further improvement. The poor implementation and strict adherence to lifestyle interventions in PHC hypertension management, such as reducing salt intake, regular exercise, smoking cessation, limit alcohol consumption, were estimated to lead to compromised health outcomes and tremendous economic losses, thus improving knowledge and skills continually of LHWs to facilitate patients to sustain a pattern of long-term comprehensive hypertension management should be another initiative.[4,5]

Disparities of Hypertension Management Knowledge Across Individual And Regional Factors Were Reduced By Training

Individual factors associated with variations in the knowledge of hypertension management decreased substantially after training. Specifically, LHWs above 60 years old were most likely to acquire excellent grades in the pre-test, which may be mainly attributed to their rich working experience. After training, LHWs aged 30-59 showed the best performance. This change suggested that PICA can improve the performance of the backbone force in PHC hypertension management independent of their working experience. Younger age was associated with limited working experience and poorer performance, and the gap between junior and senior LHWs was narrowed by training.[26,38,39] For education background, LHWs with college degrees were inclined to acquire excellent grades owing to a 5-year medical education, and PICA reduced those disparities between LHWs who had college degrees and those who had not.[5,38-40] Notably, LHWs who worked in urban areas and center institutions showed a higher likelihood of getting excellent in both pre- and post-tests, whereas the disparities between urban/rural and center/branch were substantially reduced after training.[4,5,40] In spite of those statistical differences in performance within subgroups still ing, web-based training strategies were proved to be effective and had the potential to eliminate regional and institutional disparities in hypertension management knowledge among LHWs, especially in the consideration of large sample size in real-world implementation.

Socioeconomic contextual factors explained over half of the interprovincial differences in acquiring excellent grades before and after training, while individual factors did not explain much of the variations, which was consistent with previous studies: compared with self-initiated in-service training which largely related to individual characteristics, receiving tailored and high-quality in-service training held by trainers would be a more effective way to enhance knowledge.[9,41] Thus the importance of macro-environmental supports in in-service training for LHWs rather than self-teaching should be emphasized, such as policy action and financial inputs.[10]

Implications

With the wide range of accessibility, the high proportion of certification, and the substantial improvement of capacity, the implementation of web-based in-service training with unified standards proved to be an effective and efficient way to launch nationwide public health campaigns among LHWs. It is inconceivable to improve hypertension management knowledge among millions of LHWs within 1-year, especially in a vast country where geographical variations in capacity and expertise exist. Owing to the popularization of the internet and wide access to the internet in the country, the training turned out to be extraordinarily workable. During the past three years, the COVID-19 pandemic has spurred the creative deployment of digital technology and integrated platforms to enhance the roles of healthcare systems worldwide, and it was an optimal chance to deeply promote the web-based training of hypertension management as part of its evolution, particularly to evaluate experiences acquired domestically and generalize to other LMICs with huge inputs towards PHC system to train LHWs like China. For better performance of web-based training in local contexts, we suggest that, first, the training materials need to be tailored and evaluated for local PHC settings under the unified framework, which contains feasible, affordable, practical, and contextualized recommendations. Second, regular feedbacks by use of post-training satisfaction surveys among participants are needed, these personal opinions would facilitate the organizers to

fully acquire and understand LHWs' needs regarding the knowledge of hypertension management, covering the aspects of participants' willingness, accessibility, adherence, as well as training design, contents, materials, approaches, periods and evaluations. In response to problems raised in feedback, and weaknesses of specific knowledge points presented in training evaluation, proper adjustment and modification could be initiated to comprehensively improve the performance of training quality in the long -term. Third, in-service training tools that are designed to extend through personal terminals like laptops and mobile phones should be linked with the learning system. In this way, such a digital learning PHC system that engages LHWs can potentially update and evaluate their knowledge to continuously improve their professional capacity.[4,5,7]

Strengths and Limitations

A strength of the current study is that the PICA training was implemented in real-world settings and covered more than one million LHWs from areas of diverse geographical and economic characteristics. Thus our promising findings may have the potential to be well generalized to other LMICs. Additionally, the usage of multilevel analysis facilitated the study to reveal the geographical variations of training effectiveness and interpret the contributions of both individual and regional level factors to those variations. However, this study was also subjected to several limitations. First, of 4.67% participants filled incomplete or didn't complete the post-test were excluded from the study, which may slightly overestimate the training effectiveness. The second, ecological fallacy may appear when analyzing provincial-level socioeconomic contextual factors of training effectiveness so these associations might be underpowered. Second, we collected information about the number of hypertensive patients cared for by each LHW, which may influence the training effectiveness.[10]

Conclusion

We demonstrated the effectiveness and feasibility of using a web-based strategy to provide large-scale national in-service training for LHWs in PHC settings to enhance professional knowledge about hypertension management. Substantial variations of hypertension management knowledge were observed across individual characteristics, geographical areas, and contextual correlates before training, and those disparities were considerably reduced by training. Geographical variations were shown at the provincial level, with the majority of them being explained by factors at the regional level. Accessible web-based training modality, and government efforts, accompanied with experiences derived from PICA, could be generalized to other LMICs in facilitating the hypertension management capacities of LHWs. Moreover, localization adjustment is needed and subsequent evaluation is warranted on the way to its further application worldwide.

DISCLOSURE

Contributors

JL conceived and designed the study. JL had full access to all the data in the study, and took responsibility for the integrity of the data. WW performed the statistical analysis. WW prepared and finished the first draft based on comments from other authors. JL, HZ, JML, and YL, critically revised the manuscript for intellectual content. JL, HZ, JML, YL, NT, LY, JXS, MLL, and YP provided administrative, technical, or material support. All authors reviewed, provided critical inputs for revision, and approved the final manuscript.

Ethics Approval and Consent Participate

As the data used were collected for working purpose and authors have no access to information that could identify individual participants, the ethics approval was waived.

Availability of Data and Materials

The data are not publicly available.

Declaration of Interests

None.

Acknowledgments

The authors thank all involved national, provincial, and local health administrative departments, and primary health care institutions for their participation and contributions.

REFERENCES

[1] Roth GA, Mensah GA, Johnson CO, *et al*. Global burden of cardiovascular diseases and risk factors, 1990-2019: update from the GBD 2019 study. *J Am Coll Cardiol* 2020; 76: 2982−3021.

[2] Liu S, Li Y, Zeng X, *et al*. Burden of cardiovascular diseases in China, 1990-2016: findings from the 2016 global burden of disease study. *JAMA Cardiol* 2019; 4: 342−352.

[3] Chen Z. Launch of the healthcare reform plan in China. *Lancet* 2009; 373: 1322−1324.

[4] Li X, Krumholz HM, Yip W, *et al*. Quality of primary health care in China: challenges and recommendations. *Lancet* 2020; 395: 1802−1812.

[5] Li X, Lu J, Hu S, *et al*. The primary healthcare system in China. *Lancet* 2017; 390: 2584−2594.

[6] Liang S, Deng H, Liu S, *et al*. Competency building for lay health workers is an intangible force driving basic public health services in southwest China. *BMC Health Serv Res* 2019; 19: 596.

[7] Hu S. Scalable hypertension management tools in communities based on novel technologies in China. *Lancet Reg Health West Pac* 2022; 29100619.

[8] Lu J, Lu Y, Wang X, *et al*. Prevalence, awareness, treatment, and control of hypertension in China: data from 1.7 million adults in a population-based screening study (China PPeace Million Persons project). *Lancet* 2017; 390: 2549−2558.

[9] Rowe AK, Rowe SY, Peters DH, Holloway KA, Chalker J, Ross-Degnan D. Effectiveness of strategies to improve health-care provider practices in low-income and middle-income countries: a systematic review. *Lancet Glob Health* 2018; 6: e1163−75.

[10] Rowe AK, Rowe SY, Peters DH, *et al*. The effectiveness of training strategies to improve healthcare provider practices in low-income and middle-income countries. *BMJ Glob Health* 2021; 6: e003229.

[11] Vaona A, Banzi R, Kwag KH, *et al*. E-learning for health professionals. *Cochrane Database Syst Rev* 2018; 1D11736.

[12] Bell M, Macdougall K. Adapting online learning for Canada's northern public health workforce. *Int J Circumpolar Health* 2013; 72.

[13] Khachatryan L, Balalian A. Performance assessment through pre- and post-training evaluation of continuing medical education courses in prevention and management of cardiovascular diseases in primary health care facilities of Armenia. *J Community Health* 2013; 38: 1132−1139.

[14] Nieder J, Nayna SP, Sauerborn R, Barteit S. Massive open online courses for health worker education in low- and middle-income countries: a scoping review. *Front Public Health* 2022; 10891987.

[15] Martinez-Valverde S, Castro-Rios A, Perez-Cuevas R, Klunder-Klunder M, Salinas-Escudero G, Reyes-Morales H. Effectiveness of a medical education intervention to treat hypertension in primary care. *J Eval Clin Pract* 2012; 18: 420−425.

[16] Edward A, Kumar B, Kakar F, Salehi AS, Burnham G, Peters DH. Configuring balanced scorecards for measuring health system performance: evidence from 5 years' evaluation in Afghanistan. *PLoS Med* 2011; 8: e1001066.

[17] Xu W, Jiang Q, Qin X, Fang G, Hu Z. E-learning for grass-roots emergency public health personnel: preliminary lessons from a national program in China. *Biosci Trends* 2016; 10: 235−239.

[18] Meina Z, Annisa RS, Mimi ML. A comprehensive systematic review of MOOC research: research techniques, topics, and trends from 2009 to 2019. *Educ Technol Res Dev* 2020; 68: 1685-1710.

[19] Ballew P, Castro S, Claus J, Kittur N, Brennan L, Brownson RC. Developing web-based training for public health practitioners: what can we learn from a review of five disciplines?. *Health Educ Res* 2013; 28: 276−287.

[20] Cook DA, Levinson AJ, Garside S, Dupras DM, Erwin PJ, Montori VM. Internet-based learning in the health professions: a meta-analysis. *JAMA* 2008; 300: 1181−96.

[21] Nartker AJ, Stevens L, Shumays A, *et al*. Increasing health worker capacity through distance learning: a comprehensive review of programs in Tanzania. *Hum Resour Health* 2010; 830.

[22] Khatony A, Nayery ND, Ahmadi F, *et al*. The effectiveness of web-based and face-to-face continuing education methods on nurses' knowledge about aids: a comparative study. *BMC Med Educ* 2009; 941.

[23] Frehywot S, Vovides Y, Talib Z, *et al*. E-learning in medical education in resource constrained low- and middle-income countries. *Hum Resour Health* 2013; 114.

[24] Blankstein U, Dakurah T, Bagan M, Hodaie M. Structured online neurosurgical education as a novel method of education delivery in the developing world. *World Neurosurg* 2011; 76: 224−230.

[25] Khoja S, Scott RE. Creating e-learning resources in preventive medicine for developing countries. *J Telemed Telecare* 2007; 13: 105−06.

[26] Edward A, Kagaruki GB, Manase F, Appel LJ, Matsushita K. Effectiveness of instructional videos for enhancing healthcare provider competencies for hypertension management - a pre-post study in primary healthcare settings, Tanzania. *BMC Health Serv Res* 2022; 22: 721.

[27] Thai T, Nguyen KT, Pham TT, *et al*. Can combined online and face-to-face continuing medical education improve the clinical knowledge and skills of family doctors in Vietnam? A cluster randomised controlled trial. *Trop Med Int Health* 2020; 25: 388−96.

[28] Wei MH, Chen XZ, Zhan XX, *et al*. The effect of a web-based training for improving primary health care providers' knowledge about diabetes mellitus management in rural China: a pre-post intervention study. *PLoS One* 2019; 14: e222930.

[29] Zhang Z, Zhan X, Li Y, *et al*. Web-based training for primary healthcare workers in rural china: a qualitative exploration of stakeholders' perceptions. *PLoS One* 2015; 10: e125975.

[30] National Bureau of Statistics. National data. Available from: https://data.stats.gov.cn/english/easyquery.htm?cn=E0103 (accessed on October 31, 2022).

[31] Liu Y, Chu Y, Yeung D, *et al*. National and sub-national levels and causes of mortality among 5-19-year-olds in China in 2004-2019: a systematic analysis of evidence from the disease surveillance points system. *J Glob Health* 2022; 1211008.
[32] Merlo J, Chaix B, Ohlsson H, *et al*. A brief conceptual tutorial of multilevel analysis in social epidemiology: using measures of clustering in multilevel logistic regression to investigate contextual phenomena. *J Epidemiol Community Health* 2006; 60: 290–297.
[33] Merlo J, Chaix B, Yang M, *et al*. A brief conceptual tutorial of multilevel analysis in social epidemiology: linking the statistical concept of clustering to the idea of contextual phenomenon. *J Epidemiol Community Health* 2005; 59: 443–449.
[34] Peters D, Chakraborty S, Mahapatra P, Steinhardt L. Job satisfaction and motivation of health workers in public and private sectors: cross-sectional analysis from two indian states. *Hum Resour Health* 2010; 8: 27.
[35] Abdel-All M, Putica B, Praveen D, *et al*. Effectiveness of community health worker training programmes for cardiovascular disease management in low-income and middle-income countries: a systematic review. *BMJ Open* 2017; 7: e15529.
[36] Li X, Wu C, Lu J, *et al*. Cardiovascular risk factors in china: a nationwide population-based cohort study. *Lancet Public Health* 2020; 5: e672–e681.
[37] Su M, Zhang Q, Bai X, *et al*. Availability, cost, and prescription patterns of antihypertensive medications in primary health care in China: a nationwide cross-sectional survey. *Lancet* 2017; 390: 2559–2568.
[38] Abdelgadir HS, Elfadul MM, Hamid NH, Noma M. Adherence of doctors to hypertension clinical guidelines in academy charity teaching hospital, khartoum, sudan. *BMC Health Serv Res* 2019; 19: 309.
[39] Mckinlay JB, Link CL, Freund KM, *et al*. Sources of variation in physician adherence with clinical guidelines: results from a factorial experiment. *J Gen Intern Med* 2007; 22: 289–296.
[40] Li X, Liu J, Huang J, *et al*. An analysis of the current educational status and future training needs of China's rural doctors in 2011. *Postgrad Med J* 2013; 89: 202–208.
[41] Casey DJ. Why don't physicians (and patients) consistently follow clinical practice guidelines?. *JAMA Intern Med* 2013; 173: 1581–1583.

Please cite this article as: WANG W, ZHANG HB, LIU JM, LI Y, TIAN N, YAN L, SONG JX, LI ML, PENG Y, LI J. Variations, effectiveness and its associated factors of a nationwide web-based hypertension management training project in China: insights from a government-led campaign for 1.2 million lay health workers. *J Geriatr Cardiol* 2024; 21(7): 733–750. DOI: 10.26599/1671-5411.2024.07.010