Spatial Allocation and Optimization of Traditional Chinese Medicine Institutions Based on Medical Service Radius: A Case Study of Zengcheng District, Guangzhou City (Postprint)

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Date: 2024-02-19T14:41:05+00:00

Abstract

Background With Traditional Chinese Medicine (TCM) being incorporated into the International Classification of Diseases 11th Revision (ICD-11), the rational allocation of primary-level TCM medical resources constitutes a critical safeguard for promoting the integration of Chinese and Western medicine and achieving universal coverage of high-quality medical resources. The uneven layout and service capacity of primary-level medical institutions have resulted in a pervasive mismatch between supply and demand of medical resources in urban and rural areas. Objective To investigate the provision of TCM services in townships across China, scientifically evaluate the coverage and accessibility of primary-level TCM diagnosis and treatment, and provide novel insights for optimizing the spatial allocation of primary-level TCM service resources, thereby proposing corresponding optimization strategies. Methods Based on data from the seventh national population census and point-based geographic spatial data, we introduced the concept of medical service radius to calculate the treatment coverage of TCM medical institutions at various levels under walking mode. Spatial kernel density index and spatial standard deviation ellipse methods were employed to reveal the spatial equity of supply and demand capacity of TCM medical services. Building upon these findings, we proposed optimization types and measures for the layout of TCM medical resources. Results As of 2022, Zengcheng District comprised a total of 699 medical institutions, including 18 TCM medical institutions with inpatient beds, with substantial disparities in bed distribution across different towns and subdistricts. Zhongtan Town ranked first among all subdistricts with 14.31 beds per thousand population. Yongning Subdistrict ranked last with merely 0.89 beds per thousand population. TCM medical institutions in Zengcheng District exhibited a pro-

nounced dual-center pattern, with residents in central Zhongxin Town, northern Paitan Town, and southwestern Shitan Town experiencing weaker availability of TCM services. Significant variations existed in TCM service supply capacity among different towns, with a certain degree of misalignment between the spatial distribution of TCM medical institutions and the overall spatial agglomeration of urban residents, and differences in TCM service radius across towns. Conclusion Since the implementation of the TCM development strategy, Traditional Chinese Medicine has been protected and developed. More scientific strategies should be adopted to closely integrate TCM services with urban development and residents' needs, actively implementing differentiated strategies that combine increasing facility points, resource transfer and decentralization, and cross-regional TCM informatization-based joint diagnosis and treatment, gradually achieving true universal coverage and the strategy of giving equal emphasis to both Chinese and Western medicine.

Full Text

A Study of Spatial Allocation and Optimization of Traditional Chinese Medicine Institutions Based on Medical Service Radius: A Case Study of Zengcheng District, Guangzhou City

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Abstract

Background: As Traditional Chinese Medicine (TCM) has been included in the ICD-11 coding system, the rational allocation of primary TCM medical resources serves as a crucial guarantee for promoting the integration of TCM and Western medicine and achieving universal coverage of high-quality medical resources. However, the uneven distribution and service capabilities of primary-level medical institutions have led to widespread mismatches between supply and demand of medical resources in urban and rural areas. **Objective:** To understand the development status of TCM services in China's townships, scientifically evaluate the coverage and accessibility of primary-level TCM diagnosis and treatment, provide new perspectives for optimizing the spatial allocation of primary TCM service resources, and propose corresponding optimization strategies. **Methods:** Based on data from the Seventh National Population Census and point-based geographic spatial data, we introduced the concept of medical service radius to calculate the treatment coverage of different levels of TCM

institutions under walking mode. Spatial kernel density index and spatial standard deviation ellipse methods were employed to reveal the spatial equity of TCM medical service supply and demand capacity. Based on these results, we proposed optimization types and measures for TCM medical resource layout. **Results:** As of 2022, Zengcheng District had a total of 699 medical institutions, including 18 TCM institutions with inpatient beds, showing significant variations in bed distribution across different townships and streets. Zhongtan Town ranked first with 14.31 beds per thousand population, while Yongning Street ranked last with only 0.89 beds per thousand population. TCM institutions in Zengcheng District exhibited a clear dual-center pattern, with residents in central Zhongxin Town, northern Paitan Town, and southwestern Shitan Town having weaker access to TCM services. The supply capacity of TCM services varied considerably among townships, with a certain degree of mismatch between the spatial distribution of TCM institutions and the overall spatial clustering of urban residents, and differences in TCM service radius between townships. **Conclusion:** Since the implementation of the TCM development strategy, Traditional Chinese Medicine has been protected and developed. More scientific strategies should be adopted to closely integrate TCM services with urban development and residents' needs, actively implementing differentiated strategies that combine increasing facility points, resource transfer and sinking, and cross-regional TCM informatization for joint diagnosis and treatment, gradually achieving true full coverage and a strategy that gives equal emphasis to both TCM and Western medicine.

Keywords: Traditional Chinese Medicine institutions; Medical service radius; Primary-level Traditional Chinese Medicine services; Spatial standard deviation ellipse; Spatial optimization

Introduction

Traditional Chinese Medicine is increasingly demonstrating unique treatment methods and concepts different from Western medicine in chronic disease prevention and epidemic treatment [1]. The inclusion of Traditional Chinese Medicine in the ICD-11 coding system provides a new opportunity for the development of TCM in China and for integrated TCM-Western medicine diagnosis and treatment, confirming the important position of TCM in human health [2]. With the continuous deepening of China's hierarchical medical system, primary-level medical forces have become key to achieving the sinking and homogenization of high-quality medical resources, especially as the current development of TCM diagnosis and treatment in primary-level medical institutions can effectively improve the shortage of medical resources in some areas [3]. The full coverage of primary-level TCM services is of self-evident importance for chronic disease prevention and epidemic treatment in China's post-pandemic era [4].

In 2022, the National Health Commission issued the "Guiding Principles for Medical Institution Planning (2021-2025)" to provide reference and basis for optimizing regional health resource allocation [5]. The guidance specifically

pointed out that while expanding high-quality medical resources, attention should be paid to balanced layout between regions, particularly in township-level areas, where the balanced development of high-quality medical resources should align with new urbanization and rural revitalization strategies. Current domestic research has focused more on spatial equity of health resources at the macro level, with relatively few studies on spatial resource allocation of TCM resources in township-level areas [6], and existing research has mostly focused on spatial difference characteristics of health resources, with little involvement in spatial layout optimization at the micro scale [7].

Therefore, this study takes the 11 townships and streets under Zengcheng District, Guangzhou City as an example, combining medical service radius with urban population distribution to explore the spatial matching degree of resource allocation for primary-level TCM institutions, and proposes optimization strategies based on Zengcheng District's future development strategy, aiming to provide new ideas for improving the accessibility of primary-level TCM medical resources from a township perspective.

1.1 Study Area

Zengcheng District is located in central Guangdong Province, eastern Guangzhou City, and the northeastern corner of the Pearl River Delta. It is both a core area of the Guangdong-Hong Kong-Macao Greater Bay Area and a national urban-rural integrated development pilot zone. Guangzhou's Zengcheng District is striving to create a national demonstration zone for primary-level TCM work, holding important strategic position in the development of Traditional Chinese Medicine.

This study selected 11 townships and streets under Zengcheng District, Guangzhou City as the research units: Paitan Town, Xiaolou Town, Zhongxin Town, Zhengguo Town, Yongning Street, Zhucun Street, Licheng Street, Zengjiang Street, Shitan Town, Xiancun Town, and Xintang Town (see Figure 1

). The district covers an area of 1,616.47 km^2. By the end of 2020, the district had a permanent population of over 1.471 million, with youth accounting for 19.28% and elderly population over 65 accounting for 7.69%. Compared with the 6th National Population Census in 2010, the urbanization rate increased from 68.47% to 73.16%, the proportion of youth decreased by 4.87%, and the proportion of elderly over 65 increased by 1.21%, indicating further deepening population aging. The central and southern parts of the district are more developed, mainly carrying integrated industrial-urban development and actively supporting national development zones; the northern region consolidates ecological resources and tourism resources, forming a spatial pattern of "south agglomeration and north optimization."

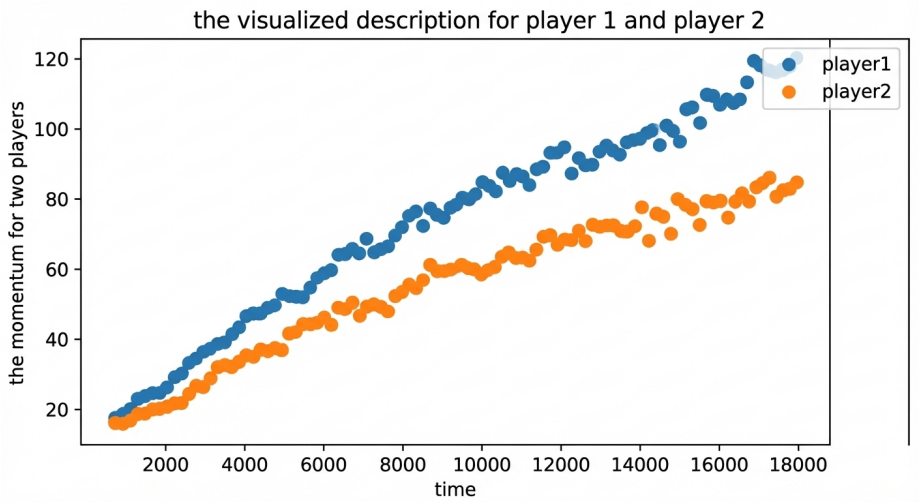

Figure 1: Figure 1

1.2 Data Sources

Basic Geographic Data: Basic geographic data includes subway lines and public transportation system data for the study area, point-of-interest (POI) data, residential community data, and elevation data. Based on Baidu Maps, we obtained 2020 POI data, residential community data, and elevation data for Zengcheng District, Guangzhou City, and performed coordinate system conversion and data cleaning. In 2020, the total road mileage within the study area was 2,275.338 km, with further improved road network structure. The district currently has 90 bus routes and 2 subway lines. By 2035, the district aims to achieve a comprehensive transportation system for both domestic and international "dual circulation" that will comprehensively cover eastern, central, and western regions.

POI Data: POI data is increasingly widely used in health-related scientific research due to its authentic geographic entity attributes [8]. Through collection, cleaning, and screening of POI data, we finally selected 22,990 POI data points and categorized them into five major categories: subway stations, bus stations, residential communities, schools, and medical institutions. Among these, medical institution POI data was used to precisely locate TCM institutions, combined with Zengcheng District's comprehensive promotion of primary-level TCM services and strengthening of TCM department construction in medical institutions. Other POI data and indicators provide support for quantifying spatial accessibility.

TCM Institution Data: As the main provider of medical services, public medical institutions can provide higher quality, more convenient, and cheaper medical services with government support and guidance. We selected non-profit

township health centers and primary/secondary hospitals with inpatient beds that can provide TCM medical services within Zengcheng District, Guangzhou City. Additionally, since Zengcheng District has established a TCM medical consortium development framework with "tertiary hospitals as the leader radiating and driving primary-level TCM development," this study also included tertiary hospitals in the research.

Based on literature and hierarchical diagnosis and treatment service system standards, TCM medical institutions were divided into three levels to measure spatial accessibility [9-10]. The first level includes township health centers and street community health service centers (3 institutions, including 1 secondary hospital branch); the second level primarily includes primary and secondary hospitals (11 institutions); the third level mainly includes tertiary hospitals (5 institutions). The spatial configuration of different levels of TCM institutions in townships is shown in Figure 2 [FIGURE:2]. Data sources: Zengcheng District Health Bureau, covering a total of 18 primary-level medical facilities with inpatient beds. (http://www.zc.gov.cn/gk/zdly/ylfwxxgk/bjtjylfwxxgk/content/post_{8774868}.html)

Population Data: Numerous empirical studies have shown that population typically gravitates toward areas rich in production materials and material resources, resulting in non-uniform distribution of urban residents within regions [11-12]. Therefore, primary-level TCM medical care can only achieve homogenization of high-quality TCM resources by fully considering population needs in different regions and coordinating with urban development strategies. Based on WorldPop and Seventh National Population Census (2020) data, supplemented by residential community location data, we measured the demand and supply of TCM medical resources.

1.3 Methods

We employed spatial kernel density index to quantify the degree of population aggregation and spatial distribution density in different townships. By drawing spatial standard deviation ellipses for different levels of TCM institutions, we analyzed the resource matching degree between TCM medical resources and local population. We measured the TCM medical service radius at different levels to provide basis for further spatial optimization. Data visualization analysis was completed using ArcGIS 10.4.

1.3.1 Spatial Kernel Density Index The kernel density index visualizes spatial aggregation by measuring the density of peripheral spatial elements [13]. A smooth surface is overlaid above element points, with surface values gradually decreasing as distance from the points increases, reaching zero at a distance equal to the search radius. It is based on a quartic kernel function calculation. The predicted density of elements (X,Y) is calculated as follows:

$$Density = \frac{1}{(radius)^2} \sum_{i=1}^{n} p_i \left(1 - \frac{dist_i^2}{radius^2}\right)^2 \quad (1)$$

For $dist_i < radius$, where i represents population element points, p_i is the resident population value, and $dist_i$ is the distance between element point i and location (x, y).

To determine the search radius, kernel density bandwidth needs to be calculated. Due to the relatively developed transportation network in the study area, Euclidean distance weighting was adopted [14]. The calculation formula is:

$$SearchRadius = 0.9 \times \min\left(SD, \sqrt{\frac{\ln(2)}{D_m}}\right) \times D_m \times n^{-0.2}$$

where D_m represents the median distance of the weighted mean center, SD is the standard distance, and ω_i is the weight of element i.

1.3.2 Spatial Standard Deviation Ellipse By drawing spatial standard deviation ellipses, we can reduce dimensions to quantify variation patterns and characteristics of elements in two-dimensional spatial patterns [15]. This process is calculated as follows:

$$SDE_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}}$$

$$SDE_y = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n}}$$

where x_i and y_i represent the geographic coordinates of element areas; w_i is the contribution degree of TCM institutions in the current area; $\bar{x}$ and $\bar{y}$ are the arithmetic mean centers; and σ_x and σ_y represent the standard deviations of the X and Y axes. The final standard deviation ellipse equation is determined based on standard deviation.

1.3.3 TCM Medical Service Radius Under Walking Mode TCM medical service radius refers to the maximum distance covered by various medical services provided by TCM institutions, i.e., the maximum walking distance for residents to reach the nearest TCM medical service facility [16]. Walking is the most basic travel mode, and the service scope of primary-level TCM medical resources under walking mode directly reflects the coverage capacity of TCM medical services in townships and streets. Based on relevant literature and

the growing trend of population aging, we determined the radiation range of different levels of TCM institutions. The setting method is as follows:

$$k = v_i \times t_j$$

where k represents the TCM medical service radius; v_i represents the average walking speed of the study population; i indicates different age groups; t represents the time for the population to reach different levels of TCM institutions; and j indicates different levels of TCM institutions. See Table 2 for details.

Results

2.1 Spatial Configuration of TCM Institutions

As of May 2022, Zengcheng District had a total of 699 medical institutions, including 18 TCM institutions with inpatient beds (including Xintang Hospital branch), as shown in Table 3 . From the perspective of township administrative divisions, the distribution of TCM institution beds across different townships and streets showed significant differences. Zhongtan Town ranked first with 14.31 beds per thousand population, while Yongning Street ranked last with only 0.89 beds per thousand population. In all townships, Zhongxin Town, Licheng Street, Zengjiang Street, Yongning Street, Xintang Town, and Shitan Town each had permanent populations exceeding one million.

Notably, the supply capacity of medical and health resources cannot be simply referenced by township administrative divisions. Therefore, we conducted comprehensive analysis combining elevation, residential communities, and transportation conditions. Except for some central and northern areas like Paitan Town with a maximum elevation of 1,088 m, Zengcheng District generally has low elevation. Additionally, subway stations are mainly distributed in the southern region with 12 stations; bus stations are widely distributed, basically covering the entire district's residential population, particularly in three major areas with concentrated populations: southern Zhongxin Town, Xintang Town, and the junction of Licheng Street and southern Zengjiang Street, where the public transportation network is more developed. Based on this, residential communities are mainly distributed along railway lines, concentrated in Xintang Town and the junction area of Licheng Street and southern Zengjiang Street; residential housing shows obvious spatial agglomeration and sporadic distribution in some areas, as shown in Figure 2 [FIGURE:2].

Further analysis of the spatial matching degree between population density and TCM institutions in different townships and streets of Zengcheng District shows that TCM institutions are mainly concentrated in densely populated areas, with spatial matching degree basically consistent with population density. However, TCM medical service coverage remains weak in some areas of Paitan Town, Zhongxin Town, and Shitan Town, as shown in Figure 3 [FIGURE:3].

2.2 Spatial Matching Between Different Levels of TCM Institutions and Residents

Combining spatial standard deviation ellipse analysis with population kernel density results, the spatial matching between TCM medical resources and urban residents in different townships of Zengcheng District shows that the spatial agglomeration degree of TCM medical resources is basically consistent with that of urban residents. The directional angle of TCM institutions is 49.6777°, while that of residential communities is 51.5269°, indicating a certain degree of mismatch between spatial distribution and population distribution.

Further analysis of different levels of TCM institutions reveals that tertiary hospitals have some deviation from the distribution direction of population residential points, and are mainly distributed in the central urban area, while residents are more dispersed, showing a clear southwest-northeast trend with the smallest spatial area (0.0158), indicating low matching degree between tertiary hospitals and population demand. Primary and secondary hospitals and township health centers show a clear east-west distribution, with standard deviation ellipse areas and directions relatively close to those of residential communities, presenting a pattern of adjacent multi-level medical resource centers. However, blank areas of TCM institutions appear in northern Zhongxin Town and southern Shitan Town, lacking relatively complete TCM medical resources. Other areas like Paitan Town and Zhengguo Town have scattered TCM medical services with weak regional coordination capacity.

2.3 TCM Service Radius Range

Further investigation into the allocation level of TCM services in townships and streets and residents' accessibility to medical services shows that different levels of TCM medical service radius present multi-center spatial characteristics under walking mode, with obvious differences in service radius between townships, as shown in Figure 5 [FIGURE:5]. Overall, most urban residents in the study area can reach tertiary hospitals within 60 minutes, with medical service radius basically covering most urban residents, while other townships and streets are effectively supplemented by primary and secondary primary-level TCM institutions. However, from a global perspective, service blind spots still exist in some areas such as central and northern Zhongxin Town, central and southern Paitan Town, and central Shitan Town, where TCM medical service accessibility needs improvement and the coverage of primary-level TCM medical services needs expansion. Primary-level TCM medical institutions need continued increase. Northern Zhongxin Town, central and southern Paitan Town lack corresponding TCM institutions, while in densely populated Xintang Town, TCM institutions need optimization to improve primary-level TCM service accessibility.

2.4 Optimization Strategies for TCM Institutions

Empirical research finds that the supply capacity of primary-level medical services greatly affects local residents' life satisfaction and quality of life [17]. When the medical service radius of primary and secondary TCM institutions cannot cover local urban residents, patients can only seek medical services at tertiary comprehensive hospitals at greater distances, directly increasing patient medical costs. Therefore, leveraging the leading role of tertiary hospitals to radiate to surrounding areas, increasing primary and secondary primary-level TCM institutions, and actively promoting TCM medical consortium construction can effectively alleviate the current shortage of high-quality medical resources and further promote the implementation of the hierarchical diagnosis and treatment system in the TCM field, as shown in Figure 6 [FIGURE:6].

While actively implementing the 错位发展 (complementary development) of key TCM specialties, we should promote "Internet Plus TCM Construction," integrating characteristic diagnosis and treatment plans from different TCM institutions into systematic TCM advantage disease treatment guidance plans. Particularly in "epidemic prevention and chronic disease management," we should fully leverage TCM's characteristics of being "simple, convenient, economical, and effective," sinking priority high-quality TCM resources to primary-level township health centers, and even enabling precise diagnosis and effective referral at primary-level TCM institutions when facing difficult and complicated diseases. This maximizes matching of residents' medical needs and saves social and family medical costs, as shown in Figure 7 [FIGURE:7].

On this basis, we should further carry out regular rounds, remote consultations, business training, and other work, forming a normalized mechanism to bring high-quality TCM medical services to the most primary level.

Discussion

3.1 Increase TCM Institutions and Expand Service Radius

The residents of Zengcheng District are mainly concentrated in three major areas: southern Zhongxin Town, Xintang Town, and Lihu New City, i.e., areas surrounding intercity subway stations. There remain certain gaps in the level, quantity, and scale of TCM institutions across different townships and streets. In response to spatial mismatch contradictions between supply and demand of primary-level TCM medical institutions in different townships, we can increase matching TCM institutions in the local townships and streets based on local population structure and agglomeration degree, while fully leveraging the advantages of complementary specialty development. Meanwhile, the current service radius of TCM institutions can only satisfy most urban residents, requiring further expansion of TCM medical service coverage. Therefore, we can actively promote the integration of social capital into primary-level TCM institution construction to alleviate the weak institutional coverage caused by population mobility and urban development [19].

3.2 Accelerate TCM Informatization and Leverage TCM Advantages

The development model of medical institutions within urban areas typically involves "incubating" new campuses from old hospitals. With the deepening development of TCM medical consortia, TCM institutions should strengthen cooperation across different levels, enhance the sinking and radiation of high-quality TCM resources from central urban areas to primary-level areas, while also strengthening horizontal medical mutual assistance and cooperation [20]. In the selection of tablets, prescriptions, and traditional Chinese medicine granules, we should fully consider patient convenience and economy to meet personalized needs [21]. In the process of creating a national demonstration zone for primary-level TCM work, we should fully utilize the power of the Internet to accelerate information sharing and resource mutual assistance between TCM and Western medicine institutions, fully integrating fragmented TCM medical resources [22]. We should realize a TCM-Western medicine integrated "Zengcheng TCM Service Model" with distinct TCM characteristics, spanning from TCM universities and tertiary hospitals to primary-level TCM institutions. We should leverage the unique advantages of TCM in epidemic emergency response and chronic disease prevention, forming a scientific, reasonable, systematic, continuous, and flexible multi-level TCM medical service system to enhance China's capacity to respond to disease risks [23].

3.3 Match Urban Future Development Plans and Optimize Spatial Layout

The spatial optimization of TCM institutions should not only solve current supply-demand mismatch problems but also fully consider potential new "supply-demand mismatches" that may arise in the future. Specifically, in the next 10 years, Zengcheng District will build a Guangzhou eastern hub center and Zengcheng central urban area based on the currently most densely populated Xintang Town and Lihu New City, creating a "Zhongxin-Zhucun" development pole. Therefore, the optimization strategy for TCM institutions in Zengcheng District's "central-southern integrated area" should fully consider population mobility brought by development, focusing on basic TCM diagnosis and treatment, and prioritize increasing a large number of primary-level TCM institutions to match potential future medical demand. For the ecological development demonstration zone in northern Zengcheng, we can fully leverage TCM advantages to build a distinctive TCM big health industry, promoting regional characteristic development and health preservation. This would enable a broader integration path of ecological resources and TCM services, forming a virtuous closed loop.

This study explores the medical service radius of township TCM institutions in Zengcheng District, Guangzhou City based on urban planning data and population spatial density with a diameter of 1 km. Using spatial standard deviation ellipse, population kernel density, and other research methods, we measured the medical service supply capacity of TCM institutions in Zengcheng District un-

der walking transportation mode, and proposed spatial optimization strategies for TCM institutions based on empirical results and urban planning.

Funding: National Natural Science Foundation of China (71774079, 81973979); Guangdong Provincial Natural Science Foundation (2019A1515011496); Guangdong Provincial Social Science Fund Project (GD19CSH04)

Author Contributions: LI Chengcheng conceived the study, created figures, analyzed data, and wrote the initial draft; HE Kaiyue and LIU Ailing collected materials; LIANG Shanshan cleaned and organized data; GAO Jing revised the manuscript; ZHONG Ailin organized literature; ZHOU Shangcheng was responsible for quality control and review.

Conflict of Interest Statement: The authors declare no conflicts of interest.

Received: 2023-07-10 **Revised:** 2023-12-15 **Accepted:** 2024-01-11 (Note: This appears to be a placeholder as the actual acceptance date isn't clearly shown in the text) **Editor:** ZHAO Yuecui

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Figures

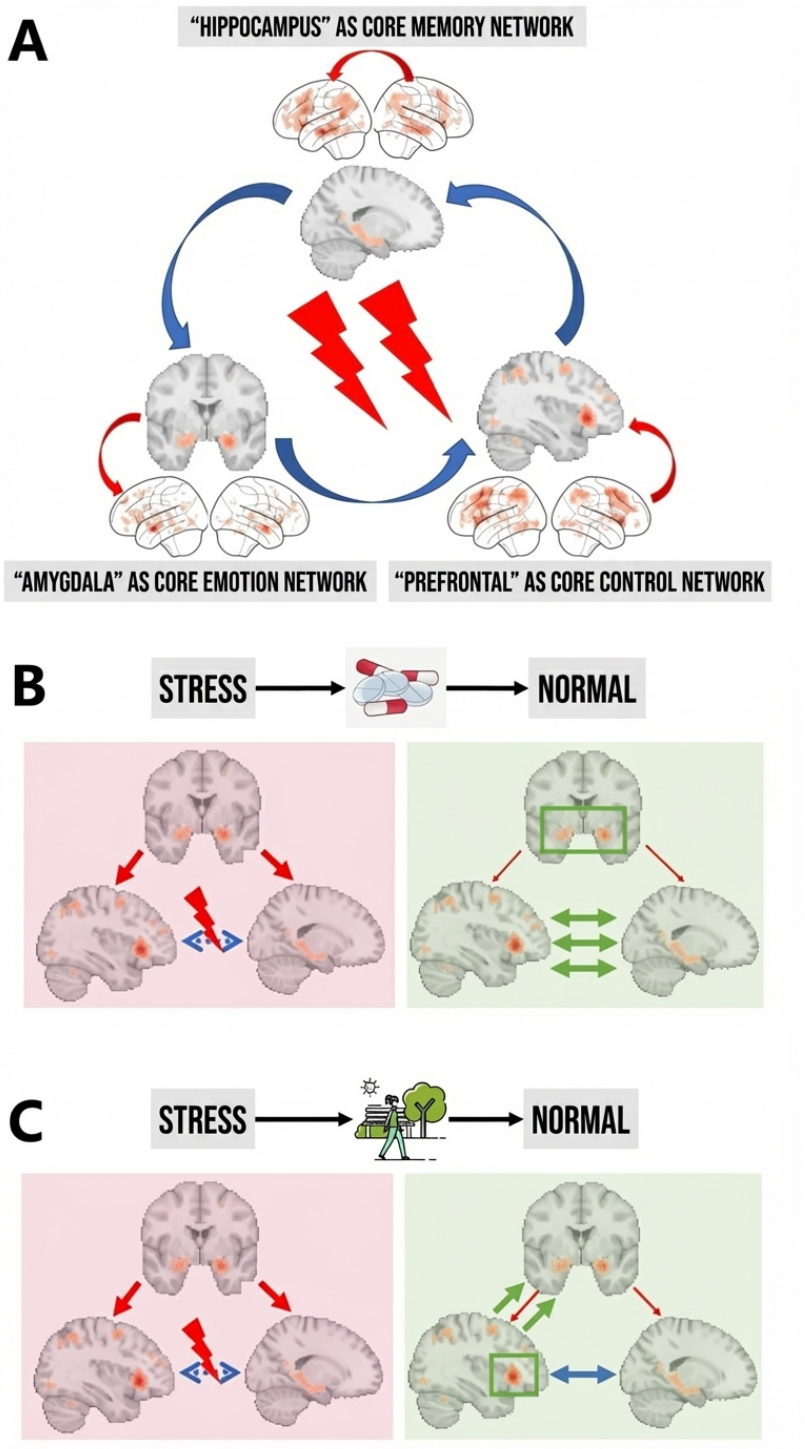

Figure 2: Figure 4