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Healthy Lifestyle Matters: A Network Analysis of Urban Chinese Pre-School Children's Adiposity, Sleep Health, Mental Health, Child Functioning and Health Behaviours

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ABSTRACT

Background: In the Chinese context, a greater emphasis is placed on academic skills rather than healthy lifestyles among pre-school children. To promote well-being as a whole, a comprehensive interpretation of multivariant relationships between health, functioning and well-being is necessary for children in this age group.

Methods: The current study adopted a network analysis among 422 urban Chinese pre-school children (57.8 ± 9.7 months, 54.2% boys) to detect the inter-relationships between the variables from nine domains, including demographics, adiposity, physical activity levels, executive function, motor coordination, sleep disturbance, diet health and mental strengths and difficulties. Data was obtained through both questionnaires completed by parents and direct assessment among children.

Results: Findings indicated that poor well-being outcomes were prevalent among the participating children, including risk of central obesity (18.9%), global sleep disturbance (38.4%) and moderate-to-severe mental difficulties (42.6%). The network analysis demonstrated that age fully/partially mediated the associations among child functioning such as executive function and motor coordination. Mental strength, mental difficulties and sleep health had mutual correlations, however, none of them had a significant relationship with age. Furthermore, sex played little role in the network.

Conclusion: This study supports that healthy lifestyle is crucial for Chinese pre-school children to learn and practice. Results of network analysis implies that education on child's mental health are warranted for children, parents and teachers. A balance between academic achievement and child's health well-being should be prioritized in child care and early childhood education.

Yuan Fang and Jing Liu contributed equally to this work.

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Summary

- Interventions of healthy lifestyles are warranted to start from early childhood.
- Network analysis was conducted for pre-schoolers' health and functioning.
- Poor well-being outcomes were prevalent among the participating children.
- Child's age mediated the variables of child functioning, but not for their mental health.
- Education of a child's mental health is necessary for children, parents and teachers.

1 | Introduction

The general health and well-being of young children play the central role in child development and positively interact with their functioning (National Academies of Sciences, Engineering, and Medicine 2015). Thereof, healthy lifestyles bring benefits to an individual's physical and mental health throughout the lifespan (Ziglio et al. 2004). Learning and practicing healthy lifestyles since early age may protect children against childhood/adult obesity, cardiometabolic diseases and psycho-social issues, and contribute to their rapid development (O'Loughlin et al. 2022). Nonetheless, researchers and policy makers recognize that health behaviours (including physical activity, healthy eating, psychological/behavioural regulation, etc.) are often difficult to change (Mollborn et al. 2014). Thus, it is important to build up healthy lifestyle habits in early age when behaviour patterns are shaped, which would make these habits more likely to be maintained throughout the life course (Jakobovich et al. 2023). Therefore, lifestyle interventions are warranted to start from early childhood (Şenol and Şenol 2023).

However, in Chinese culture, parents and schools usually perceive children's academic success and school performance as higher priorities than healthy lifestyle habits (Zhu 2009; Zhu and Zhang 2008). Therefore, the mainstream Chinese playgroup and kindergarten training commonly emphasize academic skills, which require a higher level of child functioning, rather than healthy lifestyles (Zhang et al. 2019). In accordance, previous studies showed that the levels of numeracy and literacy skills were negatively associated with emotional self-regulation in Chinese kindergarten children (Huang et al. 2022); and such negative influence on mental health may be aggravated via peer pressure later when school starts (Chen et al. 2023). Better quality children's programs/services are needed to balance the development of different skills/competence and healthy lifestyles (Su et al. 2021).

Multiple domains of a child's indicators are highlighted by the childcare guidelines across countries (Şenol and Şenol 2023; Siu et al. 2015; Su et al. 2021), such as the Reference Framework for Preventive Care for Children in Primary Care Settings. These key domains include nutrition, physical activity, safe and health behaviours, mental and psychological well-being, sleep habits, growth and functioning development, oral and visual health and family well-being. Thus, a comprehensive interpretation and understanding of the multivariate relationships between a child's physical health, mental health, child functioning and health behaviours could inform a proper selection of target behaviours when designing child services or programs.

Traditional statistical approaches (e.g., regression) usually present the study outcomes in single values, which may not be able to capture the complex interrelationships embedded in the data (Felin Fochesatto et al. 2023). In contrast, network analysis is a powerful tool for understanding the structure and/or function of complex systems (Mkhitaryan et al. 2019). Network analysis adopts a perspective that the occurrence of a health outcome is a product of interrelationships between human behaviours, psychopathologic symptoms and other factors (Ouyang et al. 2023). Thus, network analysis allows researchers to identify patterns and trends in the relationships between the variables and to understand how these relationships influence the system as a whole (Mkhitaryan et al. 2019; Ouyang et al. 2023).

In the past decade, network analysis has been used to comprehensively understand the interrelationships between school-aged children's symptoms and disease/disorder (Vasa et al. 2023; Zhang et al. 2023), cognition and behaviours (Watkeys et al. 2023) and even multiple domains in child health and development (Felin Fochesatto et al. 2023; Pereira et al. 2023). However, network findings of pre-school children are still limited in terms of health, functioning and well-being. To address the knowledge gaps, the present study aimed to conduct a cross-sectional network analysis that was based on the results collected from a group of Chinese pre-school children with typical development, who were living in an urban city. Based on the aforementioned recommended domains and the capacity/interest in the research team, this study focused on child outcomes and was conducted to investigate the following research questions:

i. How is the current situation of urban Chinese pre-school children in terms of adiposity, sleep health, child functioning (executive function, motor coordination), mental well-being (mental strengths and difficulties) and lifestyle behaviours (behaviours related to physical activity, eating behaviours)?

ii. What are the multivariate relationships in the modifiable variables?

iii. How is the influence of children's demographics (age and/or sex) on these relationships?

2 | Methods

2.1 | Study Design and Participants

This analysis was based on the baseline data of an on-going prospective cohort investigating pre-school children's health, functioning and well-being. The flow chart of participants is presented in Figure 1. The baseline sample of the aforementioned cohort consisted of 422 K1–K3 typically developing preschool children (57.8 ± 9.7 months) from three kindergartens of Zhuhai, Guangdong Province, China. There is no missing data included in the final sample. The sample consisted of 218 boys

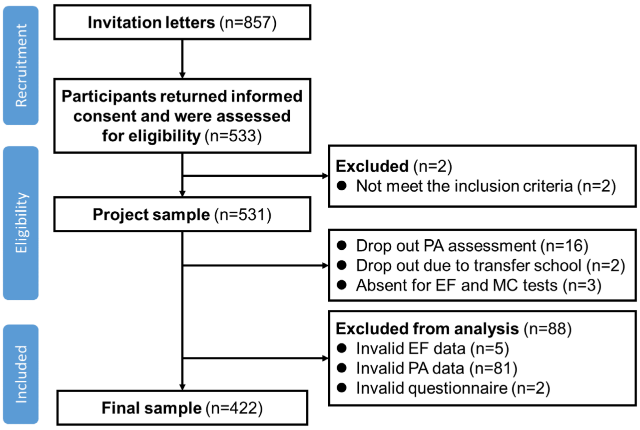

FIGURE 1 | Flowchart of participants.

(58.3 ± 9.4 months) and 204 girls (57.4 ± 10.1 months). The participating kindergartens were selected conveniently. All children aged 3–6 years with typical development in the selected kindergartens were invited to participate in the project. The exclusion criteria included (i) children who had any neuromuscular diseases/disorders, and/or intellectual disabilities; or (ii) parents/guardians of children who failed to give consent to participate in this study. Prior to the study, written consent of kindergartens and parents was obtained. The study protocol conformed to the ethical guidelines of the Declaration of Helsinki. Ethics approval was obtained from the Human Research Ethics Committee of the University.

2.2 | Study Procedures

The baseline assessment of the cohort study was conducted between September and December in 2023. Surveys were completed by parents at home, while all direct assessments of children were performed at the kindergartens by trained researchers. Informed consent forms were delivered to parents in sealed envelopes disseminated by kindergartens. All consenting parents of children received the questionnaire and instructions for completing the questionnaire in a sealed envelope. Each parent completed the questionnaire independently at home and the completed questionnaire was placed in a sealed envelope and returned via kindergartens. No incentives or financial support were provided to the participants. Research staff received one training session and two mock test sessions prior to the formal tests. They were required to strictly follow the steps and guidelines from the test manual developed by the research team. The research team provided feedback and suggestions to help research staff refine and standardize the procedures. In addition to this, 1-h in-person training was also conducted among kindergarten teachers to inform the detailed test schedule and their supports during the assessment process.

2.3 | Parent-Reported Measures of Participating Children

Demographics (i.e., age and sex) were reported by parents.

Sleep disturbance was measured by asking the parents to complete the Chinese version of Children's Sleep Habits Questionnaire (CSHQ, Liu et al. 2016). The CSHQ has 33 items and consists of eight subscales (including, bedtime resistance, sleep onset delay, sleep duration, sleep anxiety, night wakings, parasomnias, sleep disordered breathing and daytime sleepiness). Parents responded to each item with the frequency and the extent. The total score of the CSHQ, which demonstrates a behaviourally and medically based global sleep disturbance, was used in this network analysis. The internal consistency (Cronbach's α) of the CSHQ in this study was 0.80 in total (Cronbach's α of subscales ranged in 0.58–0.81).

Mental strengths and difficulties were evaluated by using the parent-reported Chinese-version Strengths and Difficulties Questionnaires (SDQ), a commonly used screening tool for emotional or behavioural problems in children aged 3–12 years (Lai et al. 2010). The SDQ has 25 items and consists of five subscales: four on mental difficulties (i.e., emotional problems, conduct problems, hyperactivity and peer problems) and one on mental strength (i.e., prosocial behaviours). Each subscale has five items, and parents rate each item between 0 and 2 (range of score for each subscale: 0–10). The summed scores from the 20 items related to difficulties (excluding prosocial behaviour) were used to calculate the total score of mental difficulties. The internal consistency (Cronbach's α) of the SDQ by this study was 0.79 in total (the Cronbach's α of subscales ranged in 0.59–0.75).

Diet health was measured by a nine-item 5-likert scale adopted from a published survey (Gui et al. 2017). The scale was answered by parents and consisted of questions regarding the frequency of consumption of certain food groups/products, ranging from 'never', 'rarely: ≤ 3 days in 10 days', 'sometimes: 4–6 days in 10 days', 'often: ≥ 7 days in 10 days', to 'always: every day'. The food category included vegetables, fruits, meat, seafood, grains, soy products, fried food or fast food, sweetened beverage and milk products. The examples of questions are: "Will your child often have vegetables consumption?", "Will your child often have fruit consumption?". According to the dietary guidelines for Chinese residents (Chinese Nutrition Society 2022), the unhealthy eating score was deemed as the summed score of consumption of 'fried food or fast food' and 'sweetened beverage', whereas the summed score of other options of food consumption was considered as an overall 'healthy eating' score. The Cronbach's α of diet health scale by this study was 0.64 (the Cronbach's α of healthy eating and unhealthy eating were 0.70 and 0.64, respectively).

2.4 | Direct Assessments on Participating Children

Adiposity was measured by children's body-mass index (BMI, kg/m^2) and waist-to-height ratio (WHtR). Height and body mass were measured via a digital height and weight scale to calculate BMI and WHtR. The height was recorded in centimetres (accurate to 0.1 cm). Body mass assessment was performed on a digital scale with a precision of 0.01 kg. The child was asked to wear light clothes and was barefoot standing during measurement. The waist circumference was measured with the help of a soft ruler with a precision of 0.1 cm. Then, the formulas 'weight [kg]/height[m]^2' and 'waist circumstance [cm]/height [cm]' were applied.

During the data collection period, the following tasks (i.e., executive function [EF], accelerometer-measured levels of physical activity [PA] and motor coordination [MC]) were conducted individually in a silent classroom from 9 to 12 am on each school day. The procedure of these assessments followed a fixed order; that is, participating children finished EF tests first and then they performed MC tests. The accelerometer was distributed on the next day after the children finished all EF and MC tests.

EF, represented by working memory, cognitive flexibility and inhibition, was measured by the following tests. The visual–spatial *working memory* was tested by the valid Corsi Block-Tapping task (CBT), which has been widely used in children aged 5–6 years (Stöckel and Hughes 2016). In this study, the CBT was administered on a screen-touched pad, and children were presented with nine blocks that sequentially lighted up. Children were asked to recall the sequence of illuminated blocks and click on the blocks in the same order. The length of the lighting up sequence started with two blocks and gradually increased to nine blocks. Two attempts were given for each length. The level of length increased if at least one attempt was tapped correctly in the former level. The task was discontinued if the child failed both attempts at the same level. The final result was the total score of the length level that was correctly recalled.

Cognitive flexibility was measured by the Dimensional Change Card Sorting task (DCCS, Zelazo 2006). Participants were required to flexibly sort out cards based on different conditions such as colour or shape. The task consists of two phases, i.e., 12-trial standard phase and 12-trial advanced phase. At the start of the standard phase, the pre-switch task required children to categorize six cards by colour (i.e., red or blue rabbits or red or blue boats, regardless of shape). The order of card presentation was fixed, and cards with the same colour were presented in no more than two consecutive trials. Followed by the post-switch task, participants were asked to sort out another six cards according to the shape. When the standard phase was finished, children were tested in the advanced phase. Twelve cards were given to children with or without black borders. Children should use the colour rule to sort out those cards with borders while the shape rule to deal with those cards without borders. Demonstration was provided prior to the formal test. Children received their final score by the total number of cards being correctly sorted.

Inhibitory control was assessed by the Head-Toes-Knees-Shoulders task (HTKS, Cameron Ponitz et al. 2008). The HTKS is a reliable and valid measurement tool with a high interrater reliability (the overall α was at 0.98, Cameron Ponitz et al. 2009). In the first part, the research staff instructed participating children to touch the head and toes as following: when the children heard "touch your head", they were required to touch their toes, and when they heard "touch your toes", they were required to touch their head. Four trials were given to train them understand the test. Accordingly, children were given 10 ordered commands to perform the formal test. Children's response to each command was graded as 2 (correct), 1 (self-corrected) and 0 (incorrect). Self-correction indicated that the movement began with an incorrect response but children corrected themselves with unstopped movement, which eventually turned to be a correct answer. In the second part, the research staff showed children how to touch knees and shoulders as following: when the command was "touch your shoulder", children should touch their knee and when the command was "touch your knee", children should touch their shoulder. These commands were mixed with "touching the head or toes". One of the four instructions was given each time, and children should act as they were instructed. Four trials were provided for children to practice and tested them with subsequent 10 commands. Each child received a sum score between 0 and 40 in these two tests.

MC among children was assessed by The Movement Assessment Battery for Children-Second Edition (MABC-2). The MABC-2 is valid among pre-school children (Ellinoudis et al. 2011) with a reliability coefficient of the total test score at 0.8 (subtests ranged from 0.73 to 0.84, Henderson et al. 2007). The MABC-2 consists of three subscales: manual dexterity, aiming and catching, and balance. According to the age range of the study participants, the motor tests specifically for age band 1 (i.e., 3–6 years old) were used. The manual dexterity subtest included three tasks (posting coins, threading beads and drawing trails) with a focus on the fine coordination of the fingers and hands. The aiming and catching subtest tested children by throwing and catching a beanbag at 1.8 m, which emphasized object manipulation and coordination in arms and hands. The balance subtest consisted of three tasks (i.e., one-leg balance, walking with raised heels and jumping on mats) to evaluate the children's capability of controlling and coordinating body parts when they needed to maintain posture and balance by either static or motional condition. Participants completed these three subtests in a fixed order. Demonstration and key points of tests were provided before formal tests. Accordingly, in each trial, each child had one practice attempt followed by two formal trials. The raw score of the best result in each trial was transformed into the standardized score. Age-related standardized scores and percentiles were provided for each subtest and the overall result of motor coordination.

PA levels were measured by an accelerometer (ActiGraph, Pensacola, FL, USA). The accelerometers were calibrated before use. Participating children were asked to wear an accelerometer on their right hip for 7 days, including five weekdays and two weekends. This data was used to estimate the time spent in sedentary behaviour and MVPA. Participating children were asked to wear the accelerometer at all times except when they are showering or swimming. Valid wear time was considered as at least 8 h per day for three valid weekdays and one valid weekend day. The sedentary time and MVPA were calculated using triaxial cut-points for pre-school children (Butte et al. 2014). Sedentary time was defined as the sum of minutes where the hip ActiGraph vector magnitude registered < 819 counts per minute (CPM). MVPA was defined as the sum of the minutes where the hip ActiGraph vector magnitude registered > 3907 CPM.

2.5 | Statistical Analysis

Mean, standard deviations and frequencies were used to characterize the sample. Independent samples *t*-test and chi-square were applied to examine the differences in study variables between boys and girls, where $p < 0.05$ indicated a significant difference.

To explore the interrelationships between all variables and the influence of a child's age and sex, three networks were proposed for the network analysis: Network 1 (all variables including sex and age), Network 2 (all variables except sex) and Network 3 (all other variables except age and sex).

The network analyses were conducted using R (Ver 4.3.2, The R Foundation, Vienna, Austria) and RStudio (Ver 2023.09.1 + 494, Posit Software, MA, USA). The Gaussian Graphical Model (GGM) was regularized using the graphical least absolute shrinkage and selection operator algorithm (Glasso) with extended Bayesian information criterion model selection (EBICglasso). The EBICglasso method included an implicit regularization mechanism; owing to this, the traditional false discovery rate (FDR) corrections were unnecessary for this study. The GGM tuning parameter was set to a conservative value of 0.5. These methods avoid false edge estimation (Epskamp et al. 2018). Hence, Glasso networks compute partial-correlation networks, meaning that relationships between variables account for all other relationships in the model, which is a very large multiple regression. According to this, all networks of this study were estimated using the *EBICglasso* function in the *qgraph* package (Epskamp et al. 2012) and script from the published studies (Galderisi et al. 2018; Levinson et al. 2018). Indices of centrality (to identify primary maintaining variables) were calculated using the *centralityPlot* and *centralityTable* functions in *qgraph* (Epskamp et al. 2012). In the visualized figures, the thickness of an edge reflects the magnitude of the correlation. Thicker and more saturated edges represent stronger correlations. Blue lines represent positive correlations, whereas red lines represent negative correlations. Nodes with the same colour belong to the same domain.

The stability of networks was tested using R package '*bootnet*' (Epskamp et al. 2016), which represents the internal reliability of the networks. In this study, edge weight stability and stability of all centralities were measured and presented by the centrality stability (*CS*) coefficients. The centrality stability coefficient represents the maximum proportion of cases that can be dropped so that there is a 95% probability that the correlation between original centrality indices and centrality of networks based on subsets is 0.7 or higher. It is suggested that for the interpretation of the centrality stability coefficient should be above 0.50 (Epskamp et al. 2018).

Node centrality difference tests, by using the R package '*bootnet*' (Epskamp et al. 2016), were conducted to determine whether the nodes that have higher centrality statistics are in fact significantly different from other nodes with lower values (Epskamp et al. 2018). Therefore, the variables would be reported in this study if they ranked in the first four places in highly central and were significantly more central than other variables in the network.

Using the '*NetworkComparisonTest*' package in R (Levinson et al. 2018), network comparison tests (NCTs) were conducted to compare if there is significant sex difference in the networks. The NCT tests invariant network structure and invariant global strength. The invariant network structure test uses an omnibus test to see if any edges in the two networks are significantly different after multiple testing corrections. In the invariant global strength test, global strength as defined as the weighted absolute sum of all edges in the network is compared across networks (i.e., the strength of the connections between variables). Thus, it is recognized if networks significantly vary based on the type of sample by using NCTs.

3 | Results

3.1 | Descriptive Results

A total of 422 pre-school children, 218 boys and 204 girls, were included in the analysis (Table 1). The mean (SD) age of these participants was 57.8 (±9.7) months. The anthropometric measurements showed that 81% of participating children had a WHtR ≤ 0.49 (normal), and 18.9% had a WHtR > 0.49 (central obesity). The parent-reported CSHQ demonstrated that 38.4% of participating children had a total score of sleep disturbance ≥ 41, which indicated a risk of both behaviourally and medically based sleep disturbance. In addition, the parent-reported SDQ indicated that 42.6% of sampled children had a moderate-to-severe situation of mental difficulty (a total score of mental difficulties > 11). Significant differences were found between boys and girls in daily MVPA levels, working memory and emotional problems ($p < 0.05$). In particular, boys significantly exhibited more favourable performance in those aforementioned outcomes than girls.

3.2 | Results of Network Analysis

The visualization of Network 1, Network 2 and Network 3 via Glasso model was presented in Figure 2. Table 2 and Figure S2 demonstrated the indices of centrality of each variable in Network 1, Network 2 and Network 3. Strength different tests of all three networks were shown in Figure S3.

Stability of networks was interpreted according to the suggested values by Epskamp et al. (2018). Thus, stability of edge weights for all three networks was good with moderate edge weight confidence intervals (all > 0.50, Figure S1). *CS* coefficients were good in three networks in terms of strength and expected influence (all ≥ 0.50, Table 3a), while the *CS* coefficients of betweenness and closeness were lower than the suggested value (< 0.50). Therefore, the present study focused on indices of strength and expected influence for interpretation.

Network 1 involved sex and age of participating children. In the Glasso analysis, variables with the highest Strength (*S*) centrality were age (demographics, $S = 2.782$), BMI (adiposity, $S = 1.178$), WHtR (adiposity, $S = 1.048$) and inhibition (executive function, $S = 0.929$). According to the strength centrality difference test, the strength centrality of age was significantly different from all 20 other variables, while the strength centrality of BMI, WHtR and inhibition was significantly different from 15, 15 and 12 other variables, respectively (all $p < 0.05$). In terms of expected influence (*EI*), variables with the highest *EI* centrality

TABLE 1 | Characteristics of participating children ($n = 422$).

Characteristics	Total ($n = 422$)	Boys ($n = 218$)	Girls ($n = 204$)	p value of independent samples t-test
	Mean (SD)	Mean (SD)	Mean (SD)	
Age (months)	57.8 (9.7)	58.3 (9.4)	57.4 (10.1)	0.202
Adiposity				
BMI (kg/m^2)	14.4 (1.8)	14.6 (1.9)	14.2 (1.7)	0.446
BMI z-score	0.0 (1.0)	0.10 (1.0)	−0.11 (0.94)	0.446
WHtR	0.46 (0.04)	0.46 (0.04)	0.46 (0.04)	0.709
Physical activity				
Sedentary behaviours (min/day)	538.1 (82.0)	529.2 (88.0)	547.5 (74.2)	0.312
MVPA (min/day)	51.9 (20.4)	57.6 (21.9)	45.8 (16.8)	0.001*
Motor coordination (standardized points)				
Manual dexterity	12.7 (2.7)	12.4 (2.8)	13.1 (2.6)	0.109
Aiming and catching	10.6 (3.1)	10.8 (3.0)	10.3 (3.1)	0.922
Balance	14.2 (3.3)	13.9 (3.3)	14.5 (3.2)	0.249
Executive function (points)				
Working memory	10.8 (11.3)	11.8 (11.9)	9.7 (10.5)	0.028*
Cognitive flexibility	19.4 (3.1)	19.3 (3.1)	19.5 (3.1)	0.746
Inhibition	26.4 (12.0)	26.1 (12.1)	26.7 (11.9)	0.968
Sleep health (points)				
Sleep disturbance (CSHQ)	43.4 (6.7)	43.1 (6.7)	43.7 (6.7)	0.902
Mental difficulties (points)	11.3 (4.1)	11.3 (3.8)	11.2 (4.4)	0.905
Emotional problems	2.0 (1.6)	1.9 (1.5)	2.1 (1.8)	0.019*
Conduct problems	2.0 (1.2)	2.0 (1.2)	2.0 (1.3)	0.193
Hyperactivity	4.7 (2.0)	4.9 (1.9)	4.5 (2.0)	0.845
Peer problems	2.6 (1.4)	2.5 (1.4)	2.6 (1.3)	0.439
Mental strengths (points)				
Prosocial behaviours	5.9 (2.0)	5.9 (2.0)	5.9 (1.9)	0.347
Diet health (points)				
Healthy eating	16.5 (4.0)	16.9 (3.9)	16.1 (4.0)	0.891
Unhealthy eating	5.6 (1.2)	5.5 (1.2)	5.6 (1.2)	0.353
	n (% in group)	n (% in group)	n (% in group)	p value
WHtR [a]				0.870
≤0.49	342 (81.0)	176 (80.7)	166 (81.4)	
>0.49 and ≤0.55	77 (18.2)	40 (18.3)	37 (18.1)	
>0.55	3 (0.7)	2 (0.9)	1 (0.2)	
Sleep disturbance (by CSHQ) [b]				0.287
<41	260 (61.6)	129 (59.2)	131 (64.2)	
≥41	162 (38.4)	89 (40.8)	73 (35.8)	
Mental difficulties (by SDQ) [c]				0.353
<12	242 (57.3)	120 (55.0)	122 (59.8)	
12–21	174 (41.2)	96 (44.0)	78 (38.2)	
>21	6 (1.4)	2 (0.9)	4 (2.0)	

Note: a. WHtR denotes waist-to-hip ratio, which indicates a central obesity if the value is higher than 0.49 and a high cardiometabolic risk if the value is higher than 0.55. b. The cut-off point of the total CSHQ score is 41, which indicates a risk of both behaviourally based and medically based sleep disturbance in children. c. Mental difficulties measured by parent-reported SDQ are indicated in a moderate situation if the sum-score of emotional problems, conduct problems, hyperactivity, and peer problems is between 12–21, and a severe situation if the sum-score is higher than 21.
*$p < 0.05$ indicates a significant difference.

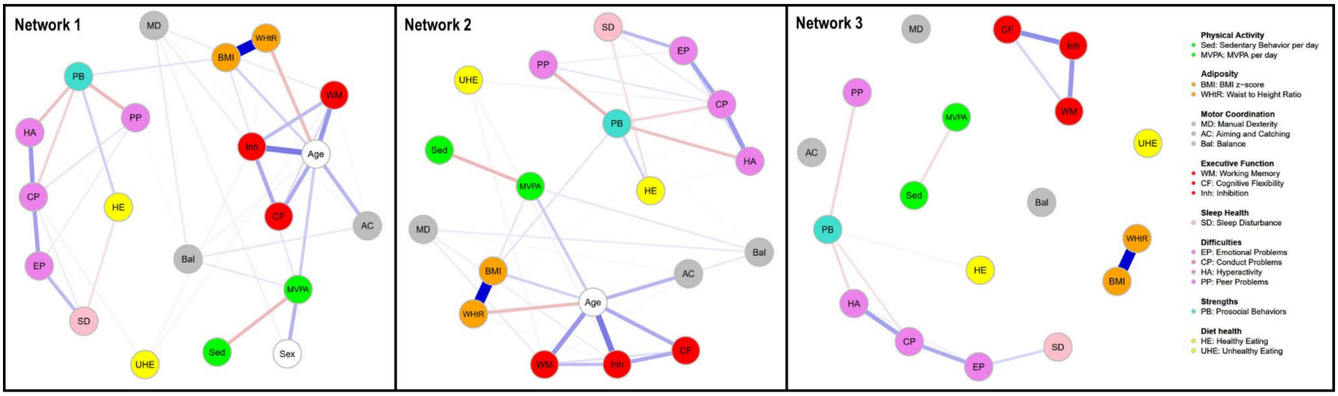

FIGURE 2 | Multivariate relationships among all study variables from a network perspective (Network 1, Network 2 and Network 3).

were age (demographics, $EI = 2.143$), BMI (adiposity, $EI = 1.725$), inhibition (executive function, $EI = 1.206$) and working memory (executive function, $EI = 0.720$).

Figure 2 showed the multivariate relationships among all study variables from a network perspective (Network 1). It was observed that the structure of Network 1 generally consisted of two divisions, age-related correlations and non-age-related correlations. In Network 1, age correlated with variables of child functioning (executive function and motor coordination), adiposity (BMI, WHtR) and physical activity (daily MVPA levels and daily sedentary behaviours). In particular, age presented a radiative relationship with multiple variables, which indicated that age may play a mediation role in those related variables (e.g., variables of executive function, daily MVPA levels and BMI). We also found that sex might bridge the interrelationships between motor function (manual dexterity) and physical activity (daily MVPA levels). In addition, a weak positive relationship may exist between daily MVPA levels and balance (see Figure 2).

However, mental strengths and difficulties, and diet behaviours did not correlate with either age or sex. In Figure 2, prosocial behaviours (mental strength) demonstrated negative relationships with variables of mental difficulties (i.e., hyperactivity, conduct problems and peer problems) but a positive relationship with healthy eating behaviours and BMI. Moreover, sleep disturbance positively correlated to emotional problems and negatively correlated to healthy eating behaviours. Furthermore, a weak positive relationship was presented between unhealthy eating behaviours and (i) conduct problems or (ii) WHtR.

Network 2 involved children's age but excluded children's sex for analysis. In the Glasso analysis, the variables with the highest four S centrality were age (demographics, $S = 2.740$), WHtR (adiposity, $S = 1.156$), BMI (adiposity, $S = 1.025$) and inhibition (executive function, $S = 0.907$). The strength centrality difference test indicated that the strength centrality of age was significantly different from all 20 other variables, while the strength centrality of BMI, WHtR and inhibition was significantly different from 15, 15 and 13 other variables, respectively ($p < 0.05$). In addition, the variables with the highest four EI centrality were age (demographics, $EI = 2.084$), BMI (adiposity, $EI = 1.677$), inhibition (executive function, $EI = 1.170$) and working memory (executive function, $EI = 0.699$). Although sex was not included in Network 2, the network structure of Network 2 was similar to Network 1. Glasso analysis showed an overall two-group structure in Network 2: variables on executive function, motor coordination and physical activity had apparent relationships with age, whereas sleep health and diet health correlated with mental difficulties and strength.

Network 3 involved neither sex nor age of participating children, which showed the interrelationships of those modifiable variables only. In the Glasso analysis, the variables with the highest four S centrality were BMI (adiposity, $S = 1.700$), WHtR (adiposity, $S = 1.700$), inhibition (executive function, $S = 1.237$) and conduct problems (mental difficulties, $S = 1.097$). According to the strength centrality difference test, the strength centrality of BMI, WHtR, inhibition and conduct problems was significantly different from 12, 12, 10 and 9 other variables, respectively ($p < 0.05$). Moreover, the variables with the highest four EI centrality were BMI (adiposity, $EI = 1.739$), WHtR (adiposity, $EI = 1.739$), inhibition (executive function, $EI = 1.347$) and conduct problems (mental difficulties, $EI = 0.722$).

Unlike Network 1 and Network 2, Network 3 only included those modifiable variables, which may be potentially intervened. However, the structure of Network 3 was obviously more disorganized than those two networks, including age, which was also reflected by the decrease of centrality stability coefficient (i.e., 0.673 in Network 1 and Network 2, while 0.595 in Network 3, see Table 3a). In Network 3, only internal relationships can be observed in variables of executive function, motor coordination and physical activity, after exclusion of age. It was evident that age might mediate the relationships between these different domains (Figure 2). Nonetheless, the structure of the other semi-network was not influenced by the absence of age; sleep health and diet health still correlated with variables of mental difficulties and strength in Network 3 (Figure 2).

Network comparison test (NCT) was conducted in the individual networks of participating boys ($n = 204$) and girls ($n = 218$) to detect sex difference in Network 2 and Network 3. Results showed that there was no significant difference (all $p > 0.05$) found in boys and girls in terms of network invariance test (M) and global strength (GS) test in Network 2 and Network 3 (i.e., Network 2: $M = 0.189$, $p = 0.297$; $GS = 0.275$, $p = 0.798$; GS of boys $= 2.435$, GS of girls $= 2.711$; Network 3: $M = 0.189$, $p = 0.233$;

TABLE 2 | Indexes of centrality per variable.

Node	Demographics		Physical activity		Adiposity		Motor coordination			Executive function			Sleep health	Mental difficulties				Mental strength	Diet health	
	Sex	Age	Sed	MVPA	BMI	WHtR	MD	AC	Bal	WM	CF	Inh	SD	EP	CP	HA	PP	PB	HE	UHE
Network 1 (including both sex and age)																				
Strength (*S*)	−0.824	**2.782**	−1.005	0.336	**1.178**	**1.048**	−0.932	−0.695	−0.906	0.292	−0.004	**0.929**	−0.601	0.091	0.731	0.060	−0.674	0.346	−0.900	−1.250
Expected influence (*EI*)	−0.401	**2.143**	−1.335	−0.064	**1.725**	0.509	−0.503	−0.100	−0.467	**0.720**	0.605	**1.206**	−0.399	0.695	0.483	−0.295	−1.079	−1.573	−0.768	−1.102
Network 2 (including age but excluding sex)																				
Strength (*S*)	—	**2.740**	−0.990	−0.233	**1.156**	**1.025**	−1.048	−0.693	−0.901	0.279	−0.012	**0.907**	−0.601	0.082	0.713	0.051	−0.672	0.334	−0.895	−1.240
Expected influence (*EI*)	—	**2.084**	−1.300	−0.594	**1.677**	0.496	−0.378	−0.095	−0.450	**0.699**	0.588	**1.170**	−0.385	0.675	0.470	−0.284	−1.043	−1.522	−0.742	−1.066
Network 3 (excluding age or sex)																				
Strength (*S*)	—	—	−0.700	−0.700	**1.700**	**1.700**	−1.085	−1.085	−1.085	0.473	0.575	**1.237**	−0.623	0.437	**1.097**	0.523	−0.630	0.222	−0.971	−1.085
Expected influence (*EI*)	—	—	−0.950	−0.950	**1.739**	**1.739**	−0.623	−0.623	−0.623	0.698	0.785	**1.347**	−0.231	0.668	**0.722**	−0.005	−1.008	−1.537	−0.526	−0.623

Note: Age: age (months); Sed: sedentary behaviours per day (minutes); MVPA: moderate-to-vigorous physical activity per day (minutes); BMI: BMI z score; WHtR: Weight-to-height ratio; MD: manual dexterity (points); AC: aiming and catching (points); Bal: balance (points); WM: working memory (points); CF: cognitive flexibility (points); Inh: inhibition (points); SD: sleep disturbance (points); EP: emotional problems (points); CP: conduct problems (points); HA: hyperactivity (points); PP: peer problems (points); PB: prosocial behaviours (points); HE: healthy eating (points); UHE: unhealthy eating (points). "—": variables excluded from networks; "NA": not applicable. Bold denotes the highest four values of each centrality measure.

TABLE 3a | Stability and network comparison test in three networks (all $n=422$).

Indicator	Network 1	Network 2	Network 3
Stability of centrality			
Edge	0.673	0.673	0.749
Strength	0.673	0.673	0.595
Expected influence	0.673	0.673	0.595
Network comparison test (boys vs. girls)			
Network invariance test (*M*, *p* value)	NA	0.189 (0.297)	0.189 (0.233)
Global strength invariance test (*GS*, *p* value)	NA	0.275 (0.798)	0.055 (0.955)
Global strength in boys ($n=218$)	NA	2.435	1.827
Global strength in girls ($n=204$)	NA	2.711	1.773
Correlation of strength centralities (*r*)	NA	0.887	0.833

Note: *p* value <0.05 denotes significant difference. NA denotes not applicable. Network 1: all variables including both sex and age; Network 2: all variables except sex; Network 3: all variables except age and sex.

$GS=0.055$, $p=0.955$; *GS* of boys $=1.827$, *GS* of girls $=1.773$). Strength centrality indices of boys' and girls' networks were highly correlated in Network 2 ($r=0.887$) and Network 3 ($r=0.833$). In summary, the way of variables' interactions and overall connectivity of the variables is similar in boys and girls of Network 2 or Network 3.

Sex difference was further explored in three sub-networks stratified by age based on Network 3 (see Table 3b and Figure 3). In the network of those samples aged 3–4 years, no significant difference was found between boys and girls in either network invariant test ($M=0.052$, $p=0.730$) or global strength invariant test ($GS=0.052$, $p=0.715$). The strength centralities are highly correlated between boys and girls ($r=1.000$). Figure 3 presents a generally disorganized network in these children. Moreover, among those children at the age of 4–5, a significant difference was revealed in global strength invariant test between sexes ($GS=0.749$, $p=0.025$; *GS* of boys $=0.321$, *GS* of girls $=1.070$), and a marginal difference was also observed in network invariant test ($M=0.232$, $p=0.095$). Thus, when boys and girls were compared in this age range, NCT showed that different variables were connected and those variables were connected in different strengths. Consistent with Figure 3, additional correlations appeared in girls' variables of mental difficulties, variables of physical activity, and prosocial behaviours—sleep disturbance—healthy eating, while boys' network was still the same as those aged 3–4 years. Furthermore, regarding the children aged 5–6 years, both boys and girls had similar networks tested by NCT ($M=0.177$, $p=0.152$; $GS=0.228$, $p=0.260$; *GS* of boys $=0.465$, *GS* of girls $=0.237$). Figure 3 shows the network of the entire samples who aged 5–6 possessed a correlation between sleep disturbance and emotional problems, which further linked to the other two mental difficulties (i.e., conduct problems and hyperactivity).

4 | Discussion

4.1 | Strengths and Importance of This Study

The current study focuses on pre-school children. It is widely recognized that both physical and mental health are playing important roles during the rapid growth and development among pre-school children (Su et al. 2021). With the perspective from public health, context-based theories may help to address the issues of childcare in particular, for example, Bronfenbrenner's bioecological theory (Avan and Kirkwood 2010). It emphasizes the crucial role of the environment and social interaction in a child's growth and development, which indicates that health promotion/education in different settings is important for both children themselves and their caregivers (i.e., parents and teachers). Thus, it is crucial for these stakeholders to comprehensively understand the interrelationships between various domains relevant to children's health and well-being, which may support their proper decision-making in childcare.

The current research adopted a cross-sectional study design to explore the interrelationships of adiposity, sleep health, mental health, child functioning and health behaviours among a group of urban Chinese pre-school children in the post-pandemic era. Although traditional statistical analysis using comparison, correlation and/or regression may exhibit one or more single facets of child development, a network analysis allows researchers to investigate the multivariate relationships from a comprehensive scope (Felin Fochesatto et al. 2023; Mkhitaryan et al. 2019). Three previous studies using network analysis in the cross-sectional study of pre-school children focused on academic skills and executive function (Bower et al. 2022; Rapuc et al. 2024), or motor skills and levels of physical activity (Bezerra et al. 2021). Consequently, this work may be the first attempt at using network analysis to investigate the interrelationships of health-related domains in pre-school children. Indicators of these domains were mainly selected based on the established Reference Framework for childcare in Hong Kong (Siu et al. 2015), where the residents share the similar Cantonese culture and local environment/climate with the study participants (i.e., they were living in Zhuhai, Greater Bay Area of China). In this study, both validated parent-administered surveys and objective measures were utilized to collect the data of participating children.

TABLE 3b | Stability and network comparison test in sub-networks of three age ranges based on Network 3.

Indicator	Year 3–4 ($n = 80$)	Year 4–5 ($n = 145$)	Year 5–6 ($n = 197$)
Stability of centrality			
Edge	0.438	0.517	0.594
Strength	0.438	0.517	0.594
Expected influence	0.438	0.517	0.594
Network comparison test (boys vs. girls)			
Network invariance test (M, p value)	0.052 (0.730)	0.232 (0.097)	0.177 (0.152)
Global strength invariance test (GS, p value)	0.052 (0.715)	0.749 (0.025*)	0.228 (0.260)
Global strength in boys	0.311 ($n = 38$)	0.321 ($n = 79$)	0.465 ($n = 101$)
Global strength in girls	0.259 ($n = 42$)	1.070 ($n = 66$)	0.237 ($n = 96$)
Correlation of strength centralities (r)	1.000	0.376	0.992

Note: p value < 0.05 denotes significant difference.

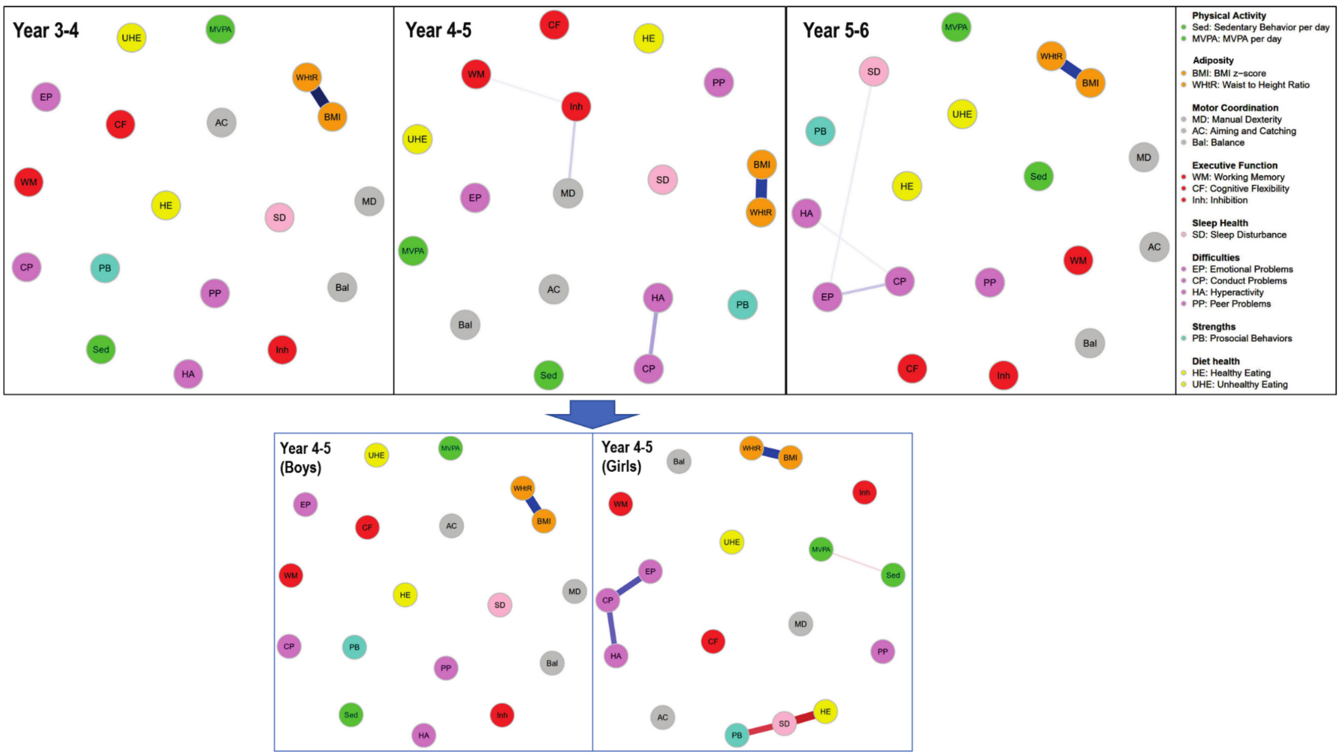

FIGURE 3 | Multivariate relationships among participants aged in different range (based on Network 3).

4.2 | Implications and Concerns Raised by This Study

Above all, the study participants were all living in Zhuhai, which is the second largest portal city in China (HKTDC Research 2022). Literature documented that urban Chinese children commonly exhibited higher levels of health status and functioning development and received higher quality of child care than their counterparts living in rural areas (Chen, Sylvia, et al. 2022; Luo et al. 2023; Su et al. 2021; Wang 2019). Such differences may be attributed to the disparities in status/conditions of family, community and environment (Chen, Sylvia, et al. 2022). Therefore, this study shed a light on the evidence of urban Chinese children, who may face distinct situations compared to their rural peers (Su et al. 2021; Zhou et al. 2020).

Owing to this, the descriptive results of this study demonstrated a preliminary situation of urban Chinese pre-school children's health and lifestyle in the post-pandemic era. First, although the BMI of participating children fell in the normal range of Chinese children aged 3–6 years (Chen, Wang, et al. 2022), the results of WHtR indicated that approximately 20% of them had the risk of central obesity (WHtR > 0.49, Eslami et al. 2022) and/or cardiometabolic risk (WHtR

> 0.55, Munoz-Hernando et al. 2022). This is consistent with literature, which found an increased prevalence of weight gain in children worldwide during the Covid-19 pandemic (Dyer 2021). This may reflect an alarming threat of paediatric obesity and call for effective weight management after the pandemic (Poon et al. 2024).

Second, the direct assessment of physical activity in participants by an accelerometer showed that participating children had an average daily MVPA level of 51.9 (±20.4) minutes and an average daily sedentary behaviour of 538.1 (±82.0) minutes, whereas girls had significantly lower MVPA levels than boys. Guidelines of WHO recommend a daily level of ≥60-min MVPA and < 60-min sedentary screen time for pre-school children (WHO 2010, 2019). Compared to this, participants of this study had a lower daily MVPA level and a concerning level of daily sedentary behaviours, which may be caused by their unhealthy lifestyles that emerged during the pandemic (Gromadai et al. 2020), especially for those children who live in a large city (Crouch et al. 2023). Therefore, interventions to promote physical activity in pre-school children are warranted in China, especially for girls (Liu et al. 2023). Of this, parent–child co-participation in PA (e.g., walking/cycling, playing sports) has been suggested by previous studies (Hnatiuk et al. 2020; Smith and Côté 2023).

Third, based on the results, parents reported that about 40% of their children encountered global behaviourally and medically based sleep problems, and around 43% of participating children had moderate-to-severe mental difficulties (i.e., girls presented significantly more emotional problems than boys). These findings are in line with previous studies, which revealed a significant correlation between a global sleep disturbance and mental problems (Liu et al. 2016). Owing to this, skills of self-regulation, coping strategies and social skills are necessarily focused on and taught in kindergartens, and the relevant training for parents and teachers is also emphasized.

Furthermore, according to the network analysis of this study, it was observed that age related to the variables of child functioning (i.e., executive function and motor coordination) in those children with typical development. This finding indicates that age may fully or partially mediate the variables between different child functions in the particular age range, which is supported by existing literature. Best et al. (2009) reported that a child's executive function, such as working memory, shifting and planning, may have developed since age 5. Consistently, Navarro-Patón et al. (2021) found that age had a main effect on pre-school children's motor competence, including manual dexterity, aiming and catching, balance (all $p < 0.001$). Accordingly, the addition of external intervening on child functioning of typically developed pre-school children may not achieve the effect as much as expected. Thus, it is questionable to put too much effort on a child's academic success and school performance at this age range (Zhu 2009; Zhu and Zhang 2008).

Nonetheless, this network analysis found that age was unrelated to the variables of their mental health in pre-school children. The similar findings were also reported by some Asian studies (Huang et al. 2022; Wu et al. 2012). The embedded reasons for this observation may be complex and still unclear—one or more factors may be involved (e.g., the limitations of measurements, the unique cultural factors of Asian context). Thus, future research may put some effort into clarifying this.

However, findings of this study may still imply that education of mental health is necessarily delivered to children from an early age. This is consistent with the findings of previous studies, which suggest that a child's psychological/mental well-being critically influences child development, school readiness and academic success. Emotional and social skills have developed since the early years in children (Im et al. 2019). Pre-school children may have viewed themselves as whole people who have a body, mind and feelings (UNICEF 2019). Previous investigations among pre-school children found that the global prevalence of psychopathology ranged from 0.1% to 26.4% (McDonnell and Glod 2003) with high rates of co-morbidity reported. This number was as high as that found in school-age children (Bufferd et al. 2012). In particular, this study showed that girls were found to be more vulnerable to mental difficulties than boys; thus, more attention shall be paid to them. In line with this, prosocial behaviours were found to positively correlate with healthy lifestyles, such as healthy eating.

As a result, this study convinced the importance of surveillance and early identification of child's mental dysfunction in different settings (e.g., eating disorder, problematic behaviours Siu et al. 2015); and the training on (a) child's emotional/social skills to protect them from mental health issues since kindergarten period (Hudson et al. 2023), and (b) their parents to improve positive parenting skills for maintaining family harmony and sufficient parent–child attachment (Avan and Kirkwood 2010; Siu et al. 2015). Consistently, similar to many other researches (Hudson et al. 2023; Jakobovich et al. 2023; Mollborn et al. 2014), this study may inform caregivers, educators and relevant stakeholders that child care and education should add more efforts on promoting emotional/social skills in pre-school children, with the aim of protecting the child's mental health at the same time to pursue their academic achievement.

4.3 | Limitations of This Study

This study still has several limitations, which require a cautious interpretation of the findings. First, a cross-sectional study design was used, whereas no causal relationships may be established based on the results. Second, the convenience sampling and a small sample size in the context of the complex networks may limit generalization of the study findings. Nonetheless, results of this study are still consistent with the findings documented in the literature, which may shed a light on a comprehensive interpretation of key points in child care. Third, parent-reported data was included in the analyses owing to the young age of pre-school children, who were not able to administer the surveys by themselves. Therefore, a recall bias and a social desirability bias in parent-reported data are possible. In addition, some subscales of CSHQ and SDQ used in this study showed a low internal consistency (i.e., Cronbach's α were < 0.60). This indicated that items within these subscales may involve a heterogeneous construct, which may be due to the different perceptions of the items among the participating parents. It implied that a cautious interpretation of the results is needed, and a revised measuring tool may be warranted because of the Chinese context and/or different performance/behaviours in preschool-age children. Fourth, the study targeted urban Chinese children, whereas the sample representativeness is limited, and the results may not be generalized to their peers in rural areas of China. Finally, future studies may wish to consider the inclusion of a wider range of variables, such as parental characteristics, familial and environmental factors.

5 | Conclusions

This study used a network analysis to interpret the health-related and functioning-related data obtained from a cross-sectional study among urban Chinese pre-school children. The multivariate relationships between the variables of nine domains discussed the role of age and sex. Results indicated that (1) age mainly correlated to child functioning but unrelated to child's mental well-being; (2) there was no significant sex difference found in the proposed networks yet; and (3) 18.9%, 38.4% and 42.6% of participating children were assessed to have potential risk of central obesity, global sleep disturbance, and mental difficulties, respectively. These findings remind an important health message to Chinese parents, educators, and stakeholders, when it comes to the child care of pre-school children—The mainstream concept should be necessarily changed, and the focus should be shifted from child's academic performance to their practice of healthy lifestyle at the pre-school age.

Author Contributions

Y.F., L.J. and F.S. contributed to the study design and professional consultation. L.J. conducted the data collection. Y.F. and M.Z. conducted data analysis. Y.F. wrote the manuscript. F.S., Z.W., S.C., C.Z. and S.B.C. reviewed the manuscript critically. All authors significantly contributed to the intellectual content of the manuscript.

Ethics Statement

The current study obtained ethical approval from the Human Research Ethics Committee of The Education University of Hong Kong (Ref No. 2022-2023-0463).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author (Dr. Fenghua SUN), upon reasonable request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Figure S1.** Edge weight confidence intervals of Network 1, Network 2, and Network 3. **Figure S2.** Centrality of Network 1, Network 2, and Network 3 (by z score). **Figure S3.** Strength different tests of Network 1, Network 2, and Network 3.