Network Analysis and Core Dimensions of Adolescent Prosocial Behavior

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Abstract

Early research has found that the concept of adolescent prosocial behavior includes four dimensions: compliance-public welfare, relational, altruistic, and trait. This study explored the network structure of the four dimensions and 15 items of prosocial behavior among Chinese adolescents (from upper elementary grades to high school, N = 9,160), and found that whether in the overall network or in networks by gender and school level, the expected influence index of the compliance-public welfare dimension was the highest, followed in order by the altruistic, relational, and trait dimensions. Network comparison results showed that neither the dimensional network structure nor the item network structure of prosocial behavior exhibited significant gender differences, but differences existed between school levels, with the overall network strength of high school students being significantly weaker than that of middle school and elementary school students. This study provides a new perspective for understanding adolescent prosocial behavior, broadens the research field of prosocial behavior, and suggests that future research could promote the development of overall prosocial behavior in adolescents by intervening in the compliance-public welfare and altruistic dimensions.

Full Text

Preamble

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Abstract
Early research has identified four dimensions of prosocial behavior concepts among adolescents: rule-abiding and public welfare, relational, altruistic, and trait-based dimensions. This study explored the network structure of these four dimensions and 15 items of prosocial behavior among Chinese adolescents (from upper elementary to high school, N = 9,160). Findings revealed that across the overall network, as well as gender- and grade-level networks, the expected influence index was highest for the rule-abiding and public welfare dimension, followed by altruism, relational, and trait dimensions. Network comparison results showed no significant gender differences in either the dimensional or item network structures of prosocial behavior, but significant differences emerged across grade levels. The overall network strength among high school students was significantly weaker than that of middle school and elementary school students. This study provides a novel perspective for understanding adolescent prosocial behavior, expands the research domain of prosocial behavior, and suggests that future interventions targeting the rule-abiding and public welfare dimension and the altruistic dimension may promote overall prosocial behavior development among adolescents.

Keywords
Adolescents, Prosocial Behavior, Network Analysis, Network Comparison, Core Dimensions

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1. Introduction

Prosocial behavior broadly refers to all actions that meet social expectations and benefit others and society (Eisenberg, et al., 2006). It is not only a crucial behavior for maintaining interpersonal, intergroup, and social harmony, but also an important indicator of individual health and well-being. Prosocial behavior promotes adolescents' mental health, social skills, and academic abilities (Wentzel, 1993), helps them establish positive social relationships with family and peers (Padilla-Walker & Carlo, 2014), and protects them from violence and antisocial behavior (Carlo et al., 2014). Adolescence represents a critical period for emotional and social development, including prosocial behavior, because adolescents' cognition and emotion (e.g., abstract thinking, role-playing, emotional labeling, and moral reasoning abilities), interpersonal relationships (e.g., face-to-face contact with peers, time spent with family), and social environments (e.g., school size, need to reorganize social roles) all undergo rapid development and change

(Baber, 2016; Goldstein et al., 2015; Opic, 2016; Steinberg, 2005). Clarifying the conceptual structure of adolescent prosocial behavior and its developmental characteristics is a major concern for researchers and educators.

Prosocial behavior is a collection of behaviors primarily characterized by outcomes beneficial to others, manifesting in various forms under different situational influences (Carlo & Padilla-Walker, 2020). For example, based on important targets of adolescent social interaction, it can be categorized as directed toward friends, family members, or strangers (Padilla-Walker, 2014). According to the purity of ultimate goals and motives, researchers propose that prosocial behavior can be driven by altruistic, egoistic, collective, or deontological motives (Batson, 2003). Carlo et al. (2002) classified prosocial behavior into six tendencies based on situational characteristics: altruistic, compliant, emotional, anonymous, emergency, and public, representing individual differences in prosocial motivation across contexts, though this theoretical discussion of motivation was largely limited to "helping behavior." Moreover, most previous research adopted a researcher-centered perspective, using simplified classification patterns to enhance internal validity in laboratory settings, but such findings were difficult to generalize effectively to real-world contexts and did not facilitate a comprehensive understanding of prosocial behavior.

Chinese scholars, adopting a "subject-centered" perspective and a "bottom-up" approach, used focus group interviews, large-scale questionnaire surveys, and laboratory experiments with Chinese adolescents to identify categories of prosocial behavior recognized by this population. Research revealed that Chinese adolescents' concept of prosocial behavior comprises four dimensions: altruism (purely for others' benefit), rule-abiding and public welfare (complying with social norms and caring for public interests), relationality (establishing and maintaining good interpersonal relationships), and trait-based behavior (maintaining good personal qualities) (Zhang & Kou, 2011). Compared to traditional prosocial behavior research that focused solely on the altruism dimension, this theory expands prosocial behavior to these four dimensions and reveals, from a "self-other-group" framework, that adolescent prosocial behavior is driven by different psychological needs (e.g., self-worth, interpersonal relationships, social value; Zhang, 2012). Subsequently, researchers developed the Prosocial Behavior Scale for Adolescents (PBSA) (Yang et al., 2016) to measure these four aspects of adolescent prosocial behavior. Although research on the conceptual structure and measurement of prosocial behavior has gradually deepened, there remains a lack of comprehensive research on the internal structure of adolescent prosocial behavior and the interrelationships among its constituent elements. This study aims to address this gap by using a large-scale sample and network analysis to examine interactions among different components of prosocial behavior and reveal its core dimensions and inter-dimensional relationships.

Network analysis is a method for exploring the interactions and internal structures among different components of a psychological construct or related behaviors through visualization (Borsboom & Cramer, 2013). Unlike cluster analy-

sis, which identifies similar objects based on characteristics, or factor analysis, which identifies latent dimensions underlying multiple observed variables, network analysis treats variable structure as an integrated network. By exploring relationships among internal components, it reveals the characteristics of different components (i.e., nodes) and their structural relationships to identify core features of a psychological concept (node centrality, key pathways or bridging roles variables play in psychological processes) (Borsboom & Cramer, 2013). In practice, understanding the internal structure and core features of psychological constructs helps design targeted psychological assessment tools or develop precise intervention and treatment programs. Boccaletti et al. (2006) noted that network analysis can be used to examine interrelationships among self-report scale items, providing insight into the associations and importance of each item within the network.

The "centrality" index in network analysis characterizes the importance of an item within the network. Network analysis has been increasingly applied in psychopathology research (Funkhouser et al., 2021; Liang et al., 2020) and personality psychology research (Costantini, Richetin, et al., 2015; Cramer et al., 2012). For example, research has found that in people' s "hopeless beliefs," factors such as "expecting more negative than positive future events," "important goals being blocked," and "feelings of giving up" are central (Marchetti, 2019). In the "dark personality," "callousness" and "interpersonal manipulation" are core features (Marcus et al., 2018). Although previous research has not directly examined prosocial behavior networks, Briganti et al. (2018) first applied network analysis to empathy research by analyzing connections among 28 items of the Interpersonal Reactivity Index, finding that the core feature was "others' misfortunes usually don' t bother me too much." These findings indicate that nodes occupying central positions in networks represent core features of psychological constructs, as they have strong connections with other nodes (Hevey, 2018). Identifying central nodes helps reveal the internal structure of psychological constructs (Briganti et al., 2018; Dalege et al., 2016) and enables the design of intervention programs around central nodes to achieve comprehensive effects (Borsboom & Cramer, 2013).

Adolescence is a critical period of rapid development in physiology, cognition, and relationships (Eisenberg, 2000). As adolescents' autonomy increases and social experiences accumulate, they may more extensively implement different types of prosocial behavior (Fabes et al., 1999), showing diverse developmental characteristics across prosocial behavior dimensions. Previous studies have found that among adolescents aged 13 to 16 and 15 to 18, both helping behavior toward strangers and volunteer service behavior increase with age (Carlo et al., 2015; Eisenberg et al., 2005), suggesting that altruistic and rule-abiding/public welfare prosocial behaviors may occur more frequently in daily life as age increases. However, not all types of prosocial behavior increase with age. For example, research found that comforting and sharing behaviors among 13- to 17-year-olds decrease with age (Luengo Kanacri et al., 2013), possibly indicating that the relational aspect of prosocial behavior gradually weakens in mid-to-late

adolescence. These findings demonstrate differentiated developmental trends in prosocial behavior across age, with different types following distinct developmental trajectories and internal mechanisms.

Additionally, research using the PBSA found that Chinese adolescents' total prosocial behavior scores begin to rise in fourth grade, peak in fifth grade, decline in middle school, and reach their lowest point in high school. However, the four dimensions show inconsistent trends: rule-abiding/public welfare and relational prosocial behaviors first increase (from fourth to fifth grade) then gradually decrease (from middle school to high school); the altruism dimension increases from elementary school to tenth grade then stabilizes; trait-based prosocial behavior remains relatively stable across grades (Zhang et al., 2015). Although this study identified differences among prosocial behavior dimensions, it did not comprehensively consider the core concept of prosocial behavior or the internal structural relationships among different types of prosocial behavior.

This study employs the Network Comparison Test in network analysis to compare global strength and structure across different networks, as well as differences in centrality and edge strength of individual nodes (van Borkulo et al., 2015). Through this statistical method, we aim to understand similarities and differences in structure, strength, and edges of prosocial behavior networks across grade levels, thereby observing whether developmental changes occur in prosocial behavior networks during adolescence.

Regarding gender differences in prosocial behavior, research generally suggests that girls are more likely than boys to engage in prosocial activities emphasizing helping, self-disclosure, and relationships (Rose & Rudolph, 2006), while boys tend to implement prosocial behavior in dangerous, emergency situations requiring physical strength (Eagly, 2009). Some studies have also found that gender differences in emotional and social development are significant, with girls generally developing faster than boys, resulting in stronger prosocial behavior tendencies among girls. For example, adolescent girls score higher than boys on all four dimensions of prosocial behavior: rule-abiding/public welfare, altruism, relationality, and trait-based behavior (Carlo et al., 2015; Zhang et al., 2015). Previous research has examined gender differences in network structures of negative outcome variables in large Chinese adolescent samples. For instance, Liu et al. (2023) found that compared to girls, boys' problematic internet use networks had higher strength, indicating greater risk.

However, no studies have examined gender differences in prosocial behavior from a network analysis perspective. Using network analysis to investigate gender differences in prosocial behavior can more finely reveal characteristics of prosocial behavior connection patterns across genders, thereby deepening our understanding and application of personalized education and intervention strategies based on gender differences. Therefore, this study plans to compare prosocial behavior networks across different grade levels and genders to identify and clarify their differences or characteristics.

Although researchers and school practitioners highly value the cultivation and enhancement of adolescent prosocial behavior, there is no consensus on the optimal timing for intervention. Researchers argue that early adolescents not only need to adapt to complex social rules but also show high sensitivity in peer interactions, making this period a common choice for interventions (Caprara et al., 2014; Mesurado et al., 2019; Wentzel et al., 2007). Network analysis provides reliable evidence for addressing this issue: it can precisely identify core components of prosocial behavior and their interrelationships across different grade levels, thereby revealing the most effective intervention target elements in prosocial behavior at different developmental stages (McNally, 2016). Considering that changing core nodes in a network may significantly impact the entire network (Blanchard & Heeren, 2020; Fried et al., 2017), activating one node can rapidly transmit connections to other nodes, thereby activating the whole network. Identifying core components of prosocial behavior will provide educators with more explicit and effective intervention targets to enhance intervention effectiveness.

In summary, this study analyzes three large samples (elementary school, middle school, and high school students) obtained from a 15-item prosocial behavior scale developed based on the four-dimensional conceptual representation of adolescent prosocial behavior. By estimating their prosocial behavior network models, we aim to (1) identify the network structure and core dimensions of adolescent prosocial behavior; (2) compare dimensional and item-level network differences in prosocial behavior across elementary, middle, and high school levels; and (3) compare dimensional and item-level network differences in prosocial behavior between boys and girls.

2. Methods

2.1 Participants

Using cluster convenience sampling, we selected students from 15 ordinary primary and secondary schools across eight provinces or municipalities (Beijing, Fujian, Henan, Jiangsu, Shandong, Shaanxi, Sichuan, and Chongqing), totaling 9,160 participants (covering elementary, middle, and high school levels: M_{{{elementary}}*{{age}}} = 10.82 years, SD = 0.74; M{{{middle}}*{{age}}} = 13.77 years, SD = 0.71; M{{{high}}_{{age}}} = 16.64 years, SD = 0.79. Detailed sample information is shown in Table 1). Data were collected in 2017. Informed consent was obtained from all schools and parents before the survey, and paper-and-pencil tests were administered uniformly in classrooms. Students could terminate participation at any time. Due to incorrect responses, omissions, and missing key variables on prosocial behavior, the questionnaires had some missing data. Missing data rates were 12.17% for elementary school (420 cases), 10.12% for middle school (248 cases), and 1.04% for high school (33 cases). Gender data missing rates were 5.20% for males (240 cases) and 6.69% for females (304 cases). Because existing network analysis methods cannot handle computations with missing values

(Epskamp & Fried, 2018), this study used the mice package in R software to impute missing values (Buuren & Groothuis-Oudshoorn, 2011) to ensure analytical accuracy and sample completeness. We performed non-parametric normal transformation on the raw data to meet normal distribution standards (Epskamp & Fried, 2018).

2.2 Measures

Prosocial Behavior Scale for Adolescents. This study used the Prosocial Behavior Scale for Adolescents to measure prosocial behavior (Yang et al., 2016). The scale consists of 15 items measuring four dimensions of prosocial behavior: rule-abiding and public welfare (5 items), relationality (3 items), altruism (4 items), and trait-based behavior (3 items). The scale uses a 7-point Likert scoring method (1 = completely disagree; 7 = completely agree), with higher scores indicating higher levels of prosocial behavior. In this study, Cronbach' s α coefficients for the four dimensions were: rule-abiding and public welfare α = 0.817; relationality α = 0.741; altruism α = 0.796; trait-based behavior α = 0.711.

2.3 Data Analysis

The data analysis included descriptive statistics and network analysis. First, we used SPSS 23.0 to conduct descriptive statistical analysis on all data to explore basic participant information and demographic variables. Second, we used R to perform network analysis to examine network structural relationships among dimensions/items of the prosocial behavior scale. Network analysis steps followed the standardized guidelines published by Epskamp et al. in 2018, including five components: network estimation, network visualization, centrality index estimation, network comparison, and network accuracy and stability estimation.

2.3.1 Network Estimation Following the standardized network analysis guidelines released by Epskamp et al. (2018), we used the qgraph package in R software to estimate partial correlation networks for the overall sample and by gender (boys and girls) and grade level (elementary, middle, and high school). Circular nodes represent dimensions/items, and lines connecting nodes are called edges, with thickness representing the magnitude of partial correlation coefficients.

For each partial correlation network, we performed the following procedures: First, we estimated a Gaussian graphical model (Costantini, Epskamp, et al., 2015), which can estimate pairwise association parameters between all nodes. Second, we used the least absolute shrinkage and selection operator (Epskamp & Fried, 2018) to avoid false positive associations. This procedure is a regularization technique that sets edges with small associations to 0 to more cautiously identify relevant edges and more accurately identify potential network structures (van Borkulo et al., 2014).

We performed visualization estimation for the overall adolescent prosocial behavior network, elementary school network, middle school network, high school network, boys' network, and girls' network. All network visualizations used the Fruchterman-Reingold algorithm. We set positive correlations as blue edges and negative correlations as red edges, with thicker lines indicating stronger connections between two nodes. Nodes clustering together indicate stronger or more numerous connections among them. To fix identical nodes in the same position across different networks for visual comparison, we used the averageLayout function in the qgraph package, which presents a consistent layout based on average positions across multiple networks.

2.3.3 Centrality Indices This study used the Expected Influence Index to measure the influence of each node in the network. The Expected Influence Index refers to the sum of edge weights connected to a node. Higher expected influence indicates greater influence within the network. Unlike traditional centrality measures, when calculating the Expected Influence Index, edge weights less than 0 are not absolute-valued but retain their sign, allowing for both positive and negative relationships in the network and providing a more comprehensive influence assessment (Robinaugh et al., 2016).

2.3.4 Network Comparison To explore gender and grade-level differences in prosocial behavior network structure, this study compared prosocial behavior networks across grade levels and genders from both global and local invariance perspectives using permutation tests. Network comparison analysis used the NetworkComparisonTest package in R software to conduct global invariance tests and local invariance tests, with significance level set at 0.05. Results below 0.05 were considered significantly different (van Borkulo et al., 2022). Global invariance tests included two parts: network structure invariance test and network global strength invariance test. The network structure invariance test explored the maximum difference in absolute values of edge weights across networks, while the network global strength invariance test explored differences in the sum of absolute values of all edge weights across networks. Local invariance tests examined differences in edge weights and node centrality indices across sample networks, with Holm-Bonferroni correction applied.

2.3.5 Network Accuracy and Stability This study used the bootnet package in R software to estimate network accuracy and stability (Epskamp et al., 2018). Edge weight accuracy was estimated through 95% confidence intervals of bootstrapped edge weights, with smaller confidence interval coverage indicating more accurate edge estimation. The centrality stability coefficient (CS) was defined as the proportion of participants that could be deleted while maintaining a correlation of 0.7 between the recalculated centrality and the original centrality index through subset bootstrapping. A coefficient greater than 0.25 indicates acceptable stability, while greater than 0.5 indicates good stability.

3. Results

3.1 Overall Sample Network

3.1.1 Network Estimation We estimated both dimensional and item-level networks of prosocial behavior, with descriptions of each node shown in Table 2 . For the dimensional network, we estimated a regularized network containing 4 nodes and 6 edges, with all 6 edges having non-zero weights (average weight = 0.28). As shown in Figure 1 [Figure 1: see original paper], each node was positively correlated with all other nodes. Rule-abiding and public welfare, altruism, and relationality clustered together with very strong pairwise interactions, while the connection between trait-based behavior and relationality was weaker, placing it in a non-core position. For the item-level network, we estimated a regularized network containing 15 nodes and 105 edges, with 93 edges having non-zero weights (average weight = 0.06). Items belonging to the same dimension tended to cluster together, but connections between items from different dimensions were also relatively strong. Specifically, PB01 and PB02 from rule-abiding and public welfare showed strong connections. PB06 from altruism showed strong connections with PB07 from relationality. PB12 from relationality also showed strong connections with PB11 from altruism and PB14 from trait-based behavior.

3.1.3 Network Accuracy and Stability Bootstrap results of edge weights for both dimensional and item-level networks (see Supplementary Material Figure 4 [Figure 4: see original paper]) and stability estimation results of centrality indices (see Supplementary Material Figure 5 [Figure 5: see original paper]) indicated that both dimensional and item-level networks had high accuracy, with CS coefficients of 0.75, demonstrating good overall stability.

3.1.4 Summary Exploration of the overall sample dimensional and item-level networks revealed high network accuracy and stability. Rule-abiding and public welfare and altruism occupied core positions in the dimensional network, with item-level network results consistent with dimensional network results.

3.2 Grade-Level Networks

3.2.1 Network Estimation To explore network structure differences and core dimensions of prosocial behavior across grade levels, we estimated dimensional and item-level networks for elementary, middle, and high school students. All three grade-level dimensional networks produced 6 edges with non-zero weights (average weights: elementary = 0.29; middle = 0.29; high = 0.28). As shown in Figure 3, the three grade-level dimensional networks showed both consistency and differences. Specifically, the strong connection between rule-abiding and public welfare and altruism existed across all three grade levels but became increasingly stronger with grade level. Conversely, the connection between trait-based behavior and relationality was the weakest across all three grade levels and became even weaker with increasing grade level.

In the item-level networks across three grade levels, each produced 105 edges, with non-zero weight edges numbering 88 in elementary, 82 in middle, and 81 in high school (average weight = 0.06 across all three grade levels). As shown in Figure 4, PB01 and PB02 from rule-abiding and public welfare showed strong connections across all three grade-level item-level networks. In elementary school, PB12 from relationality showed strong connections with PB14 from trait-based behavior. In middle school, PB12 showed strong connections not only with PB14 but also with PB11 from altruism. In high school, the relationships between PB12 and PB14/PB11 weakened.

The Expected Influence Indices for dimensional and item-level networks across grade levels are shown in Figure 5. Although the centrality ranking across all grade-level networks was consistently rule-abiding and public welfare, altruism, relationality, and trait-based behavior, differences existed across grade levels. Specifically, the Expected Influence Index for rule-abiding and public welfare was highest in middle school and lowest in elementary school, with middle and high school groups significantly higher than elementary school (p_{elementary}-middle = 0.001, p_{middle}-high = 0.32, p_{elementary}-high = 0.03). The Expected Influence Index for altruism was highest in high school and lowest in elementary school, with high school significantly higher than both elementary and middle school (p_{elementary}-middle = 0.65, p_{middle}-high = 0.03, p_{elementary}-high = 0.005). The Expected Influence Index for relationality was highest in elementary school and lowest in high school, with elementary and middle school significantly higher than high school (p_{elementary}-middle = 0.20, p_{middle}-high $<$ 0.001, p_{elementary}-high $<$ 0.001). The Expected Influence Index for trait-based behavior was highest in elementary school, slightly lower in middle than high school, with elementary school significantly higher than both middle and high school (p_{elementary}-middle = 0.001, p_{middle}-high = 0.55, p_{elementary}-high = 0.003). Across all grade-level item-level networks, the top three centrality rankings were: elementary school—PB02, PB06, PB07; middle school—PB02, PB06 tied with PB03, PB12; high school—PB02 tied with PB06, PB13, PB03 tied with PB08 for third place. PB02 from rule-abiding and public welfare ranked first across all three grade-level item-level networks. PB09 in elementary school, PB10 in middle school, and PB10 in high school had the lowest Expected Influence Indices. Detailed results of significant differences in item centrality are shown in Supplementary Material Table 3 and Figure 6.

3.2.3 Network Accuracy and Stability Bootstrap results of edge weights (Figure 7 [Figure 7: see original paper]) and stability estimation of centrality indices (Figure 8 [Figure 8: see original paper]) for grade-level dimensional and item-level networks indicated good network accuracy. CS coefficients for dimensional and item-level networks across elementary, middle, and high school were all 0.75, indicating good overall stability.

3.2.4 Network Comparison We used global and local invariance tests to compare dimensional networks across grade levels (see Supplementary Material Table 1). First, network structure invariance tests showed significant differences across grade-level dimensional networks (S_{elementary}-middle = 0.08, p_{elementary}-middle = 0.050; S_{middle}-high = 0.12, p_{middle}-high < 0.001; S_{elementary}-high = 0.18, p_{elementary}-high < 0.001). Second, global strength invariance tests also showed significant differences across grade-level dimensional networks (S_{elementary}-middle = 0.01, p_{elementary}-middle = 0.38; S_{middle}-high = 0.07, p_{middle}-high < 0.001; S_{elementary}-high = 0.08, p_{elementary}-high < 0.001). Finally, edge invariance tests revealed significant differences in edges across grade-level dimensional networks. Specifically, one edge differed significantly between elementary and middle school groups, with the connection between altruism and rule-abiding and public welfare significantly weaker in elementary than middle school ($p = 0.005$). Five edges differed significantly between middle and high school groups: the connection between altruism and rule-abiding and public welfare was significantly weaker in middle than high school ($p < 0.001$); the connection between altruism and relationality was significantly stronger in middle than high school ($p < 0.001$); the connection between rule-abiding and public welfare and relationality was significantly stronger in middle than high school ($p = 0.032$); the connection between altruism and trait-based behavior was significantly weaker in middle than high school ($p = 0.003$); and the connection between rule-abiding and public welfare and trait-based behavior was significantly stronger in middle than high school ($p = 0.034$).

Similarly, we used global and local invariance tests to compare item-level networks across grade levels. First, network structure invariance tests showed significant differences across grade-level item-level networks (S_{elementary}-middle = 0.14, p_{elementary}-middle = 0.002; S_{middle}-high = 0.13, p_{middle}-high < 0.001; S_{elementary}-high = 0.18, p_{elementary}-high < 0.001). Second, global strength invariance tests showed non-significant differences between elementary vs. middle school and elementary vs. high school item-level networks (S_{elementary}-middle = 0.02, p_{elementary}-middle = 0.82; S_{middle}-high = 0.25, p_{middle}-high = 0.04; S_{elementary}-high = 0.11, p_{elementary}-high = 0.27). Finally, edge invariance tests revealed significant differences across grade-level item-level networks, with 24 edges differing significantly between elementary and middle school groups, 24 between middle and high school groups, and 35 between elementary and high school groups. Details are available in Supplementary Material Table 2.

3.2.5 Summary Grade-level network analysis revealed that rule-abiding and public welfare was most prominent in middle school, altruism in high school, and relationality and trait-based behavior in elementary school. Significant structural and strength differences existed between dimensional and item-level networks, with high school students' prosocial behavior network strength and structure significantly weaker than middle school and elementary school stu-

dents. Regarding edge differences in dimensional networks, elementary and middle school groups differed only in the connection between altruism and rule-abiding and public welfare, while middle and high school groups showed differences in multiple dimensional connections.

3.3 Gender Networks

3.3.1 Network Estimation To explore gender differences in network structure and core dimensions of adolescent prosocial behavior, we estimated dimensional and item-level networks for boys and girls (see Supplementary Material Figure 9 [Figure 9: see original paper]). Both gender dimensional networks produced 6 edges with non-zero weights (average weight: boys = 0.30; girls = 0.30). Both gender item-level networks produced 105 edges, with 91 non-zero weight edges for girls and 90 for boys (average weight = 0.06 for both). Boys' and girls' item-level network structures showed high similarity, with both showing strong connections between PB01 and PB02 from rule-abiding and public welfare.

The Expected Influence Indices for gender dimensional and item-level networks showed high similarity (Figure 6 [Figure 6: see original paper]). In both gender dimensional networks, the centrality ranking from highest to lowest was consistently rule-abiding and public welfare, altruism, relationality, and trait-based behavior. Boys scored slightly higher than girls on Expected Influence Indices for rule-abiding and public welfare and relationality, while girls scored slightly higher on trait-based behavior, but no significant gender differences existed in centrality indices for any of the four dimensions (ps $>$ 0.05). In item-level networks, the top three items for girls were PB02, PB06, and PB08, while for boys they were PB02, PB06, and PB07. Again, no significant gender differences existed in item-level centrality indices (ps $>$ 0.05). Details are shown in Supplementary Material Table 3 and Figure 10 [Figure 10: see original paper].

3.3.3 Network Accuracy and Stability Bootstrap results of edge weights (Supplementary Material Figure 11 [Figure 11: see original paper]) and centrality stability estimation (Supplementary Material Figure 12 [Figure 12: see original paper]) for gender dimensional and item-level networks indicated good network accuracy, with CS coefficients of 0.75, showing good overall stability.

3.3.4 Network Comparison We used three tests to compare gender dimensional networks. First, network structure invariance tests showed no significant differences between gender networks (p = 0.78). Second, global strength invariance also showed no significant differences (p = 0.35). Finally, edge invariance tests showed no significant differences in any edges between gender networks, indicating that prosocial behavior dimensions are relatively stable across genders.

We used three tests to compare gender item-level networks. First, network structure invariance tests showed no significant differences (p = 0.38). Second, global strength invariance showed no significant differences (p = 0.97). Finally,

edge invariance tests revealed significant differences in only 8 edges between gender item-level networks. The connection between altruistic PB06 (“When a classmate is sick, I actively take them to the school clinic”) and relational PB12 (“After small conflicts with friends, I actively apologize”) existed only in boys' networks. Conversely, the connection between relational PB12 and trait-based PB10 (“I keep others' secrets”) existed only in girls' networks. Specific results are shown in Supplementary Material Table 2.

3.3.5 Summary Gender-specific network analysis revealed no significant differences in centrality of dimensions/items across genders, consistent with overall sample results. No significant structural or strength differences existed in prosocial behavior dimensional networks across genders, with only minor connection differences in item-level networks.

4. Discussion

Based on large samples from elementary, middle, and high school levels, this study used network analysis to deeply explore associations among dimensions and internal items of Chinese adolescent prosocial behavior, further comparing core dimensions, core items, and network structure differences across grade levels and genders. Findings revealed that the centrality index of the rule-abiding and public welfare dimension was consistently highest across the overall network and across gender- and grade-level networks, indicating its core position in adolescent prosocial behavior. Second, prosocial behavior networks showed significantly different structures across grade levels, particularly becoming looser in high school. Third, no significant gender differences existed in prosocial behavior dimensional network structure, indicating cross-gender consistency. This study is the first to examine Chinese adolescent prosocial behavior from a network association perspective, not only revealing internal structural characteristics of prosocial behavior but also providing new insights into interactions among behavioral components and developmental changes. These findings suggest that researchers investigating adolescent prosocial behavior should comprehensively consider internal relationships, complexity and differences among components, and developmental variations across grade levels.

4.1 Core Dimensions in Overall Network

Overall sample network analysis revealed that rule-abiding and public welfare and altruism dimensions occupied important positions with strong connections between them. This result is consistent with previous research showing that altruistic prosocial behavior is closely related to social responsibility (i.e., the obligation to act in ways that benefit society) (Batson et al., 2003; Carlo & Pierotti, 2020). As a core dimension of adolescent prosocial behavior, rule-abiding and public welfare aims to maintain rules of the larger social environment and promote group interests (Kou & Zhang, 2006), aligning with social norms in Chinese collectivist culture. This is also consistent with previous findings that Chinese

adolescents evaluate collective-oriented prosocial behavior significantly higher than individual-oriented prosocial behavior (Chen et al., 2002). Overall item-level network results showed that PB02 from the rule-abiding and public welfare dimension (“I am willing to do things for the class collective”) occupied a core position in the network. This indicates that for adolescents, contribution and dedication to the class collective is key to practicing prosocial behavior. In Chinese culture, collectivist spirit is highly valued, and “doing things for the class collective” reflects personal loyalty to the collective and respect for collective interests. Therefore, educators can enhance adolescent prosocial behavior by fostering class responsibility.

4.2 Grade-Level Differences in Network Structure

Grade-level dimensional network comparison results showed that rule-abiding and public welfare was the core dimension across all grade levels, with the highest centrality index in middle school. This suggests that middle school may be the most sensitive critical period for the rule-abiding and public welfare dimension. Therefore, in cultivating or promoting prosocial behavior, educators should emphasize rule-abiding and public welfare, particularly focusing on cultivating adolescents’ awareness of rules and public welfare during middle school to achieve multiplier effects. Specifically, educators can adopt intervention programs that promote prosocial behavior and emotional skills to counteract externalizing problems in adolescence, encouraging adolescents to set goals that help improve schools and classes (Caprara et al., 2014), and organizing collective game activities to establish shared goal cognition and promote peer cooperation and conflict resolution (Kou & Wang, 2003). Additionally, the altruism dimension showed the highest centrality index in high school, indicating that altruism becomes more prominent during adolescent prosocial behavior development. High school is the stage that most values the altruism dimension, possibly due to increased understanding of social responsibility and adult roles, and deeper comprehension of the positive effects of prosocial behavior (Eisenberg, et al., 2006). When promoting prosocial behavior among high school students, greater emphasis should be placed on altruistic qualities. For example, when modeling prosocial behavior, educators can highlight altruistic characteristics while cultivating empathy and helpfulness. Although relationality was a relatively weaker central dimension in the overall sample, its centrality index in elementary and middle school groups was significantly higher than in high school. Considering its intervention-friendly characteristics and uniqueness across age groups, relationality may be a high-potential intervention focus for early and middle adolescents. Relationality is rooted in adolescents’ own interactions with peers, and educators can effectively intervene on this dimension by improving social skills, communication abilities, and conflict resolution strategies according to developmental characteristics of different grade levels. Finally, although trait-based behavior had the lowest centrality in the overall network, its centrality index in elementary school was significantly higher than in middle and high school, indicating that upper elementary students place more emphasis on prosocial

behavior characteristics related to personal traits. Trait-based prosocial behavior is similar to stable personality tendencies, emphasizing behaviors related to positive personal qualities.

Our findings on grade-level network comparisons provide evidence for developmental changes in prosocial behavior network structure during adolescence. Upper elementary students showed the highest overall network strength, followed by middle school students, with high school students showing the lowest. This result indicates that prosocial behavior networks may undergo important structural changes as adolescents mature. Notably, no significant difference existed in overall network strength between elementary and middle school students, but high school students'network strength was significantly weaker than both middle school and elementary school students. The decline in global strength means decreased activation among nodes. This finding has important implications for understanding adolescent prosocial behavior development and intervention. Nodes in prosocial behavior networks are more easily activated in elementary and middle school stages, indicating that students at these levels have closely interconnected different types of prosocial behavior. Therefore, elementary and middle school stages may be the optimal critical times for intervening in adolescents' overall prosocial behavior, as interventions during these periods can maximally activate the entire prosocial behavior network, producing profound effects on adolescents' social development with multiplier benefits.

4.3 Gender Differences in Network Structure

This study found no significant centrality differences across the four dimensions of rule-abiding and public welfare, altruism, relationality, and trait-based behavior between genders, nor significant gender differences in network structure. However, some minor differences emerged in item-level gender network comparisons. For example, the connection between altruistic PB06 ("When a classmate is sick, I actively take them to the school clinic") and relational PB12 ("After small conflicts with friends, I actively apologize") existed only in boys' networks. Conversely, the connection between relational PB12 and trait-based PB10 ("I keep others' secrets") existed only in girls' networks. Based on gender socialization theory, some research indicates that girls show more caring for others during socialization, while boys may inhibit prosocial behavior intentions in certain situations (Fagot et al., 2000). Meanwhile, due to differences in gender role beliefs, boys and girls may emphasize different prosocial behavior categories. For instance, girls value loyalty and kindness, while boys may be more inclined to take action in emergency situations (Carlo, 2013). This partially explains why girls' networks show more connections related to relationship repair and secret-keeping, while boys' networks highlight reactive actions in emergency situations like helping sick classmates. Although gender differences exist in item-level networks, our results indicate cross-gender consistency in prosocial behavior dimensional networks. Considering network structure differences across grade levels, we further explored whether gender differences existed in prosocial be-

havior dimensional networks within each grade level. Results showed no gender differences in prosocial behavior dimensional networks at any grade level (see Supplementary Material Figures 1 and 2). This study further confirms that prosocial behavior network structures and centrality are similar across genders at different developmental stages.

4.4 Limitations

This study has several limitations. First, the networks were entirely based on adolescents' self-reported prosocial behavior scales, which cannot avoid social desirability effects. Future research could use observation methods, clinical interviews, and behavioral experiments to obtain richer data for comparison, or use peer/teacher ratings to reduce potential social desirability issues in self-reports. Second, although this study covered adolescent groups across three grade levels, the data were cross-sectional and sampled from only eight provinces/municipalities. Future research could use more representative national longitudinal tracking data to reveal developmental patterns and mutual influences among different dimensions/items in adolescent prosocial behavior networks.

4.5 Conclusion

This study provides important insights into the internal structure and developmental characteristics of Chinese adolescent prosocial behavior through network analysis. The rule-abiding and public welfare dimension consistently emerges as the core component across developmental stages and genders, while significant structural changes occur across grade levels, particularly network weakening in high school. These findings have important implications for targeted interventions aimed at promoting adolescent prosocial behavior development.

Supplementary Materials

Figure 7. Bootstrap confidence intervals of edge weights across three grade-level dimensional and item-level networks. Note: Red lines represent edge weight values, gray areas represent 95% confidence intervals.

Figure 8. Subset bootstrap results for three grade-level dimensional and item-level networks.

Figure 9. Visualization of gender dimensional and item-level networks. Note: Each node represents a prosocial dimension/item. Edges connecting two nodes represent partial correlations, with thickness indicating strength. Thicker edges represent stronger partial correlations, thinner edges represent weaker partial correlations. Blue edges represent positive correlations, red edges represent negative correlations.

Figure 10. Edge strength difference tests for gender dimensional and item-level

networks. Note: Black boxes indicate significant differences between two nodes, gray boxes indicate no significant differences.

Figure 11. Bootstrap confidence intervals of edge weights for gender dimensional and item-level networks. Note: Red lines represent edge weight values, gray areas represent 95% confidence intervals.

Figure 12. Subset bootstrap results for gender dimensional and item-level networks.

Table 1. Edge values and difference test results across six dimensional networks.

Table 2. Edge values and difference test results across six item-level networks.

Table 3. Centrality index difference test results for gender and grade-level item-level networks.

Note: Figure translations are in progress. See original paper for figures.