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Does accumulated family risk inhibit adolescent physical activity at home? An examination with a longitudinal latent growth model

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Abstract

Background The escalating prevalence of problem behaviors among adolescents, primarily stemming from accumulated family risk has emerged as a significant concern in contemporary school and family education. This phenomenon warrants particular attention as it may directly lead to reduced physical activity levels among adolescents within their domestic settings, potentially resulting in significant long-term consequences. Grounded in ecological systems theory, this study seeks to elucidate the cumulative effects of family risk on adolescent development. Through the application of a latent growth model across three distinct observation periods, we aim to systematically examine and clarify the longitudinal development trajectories and underlying interaction mechanisms of the variables under investigation.

Methods A simple random cluster sampling method was utilized to select four middle schools from Sichuan Province, Guangdong Province, Hebei Province, and Beijing City as the research sites. A total of 682 primary and middle school students participated in three waves of follow-up surveys. Data were collected using validated scales, including the Accumulated Family Risk Scale and the Home Physical Activity Scale, to assess the respective constructs.

Results (1) Adolescent accumulated family risk and home physical activity exhibited relative stability over the three observation periods, and a significant negative correlation was observed between these two variables. (2) The initial levels of adolescent home physical activity and accumulated family risk were significantly negatively correlated. Furthermore, these initial levels were found to significantly predict the growth rate of accumulated family risk, with the direction of influence being negative.

Conclusion The findings suggest that higher levels of physical activity and lower initial levels of accumulated family risk may serve as protective factors against the escalation of accumulated family risk levels during adolescence. These findings offer novel empirical evidence and theoretical insights for designing targeted interventions aimed at mitigating accumulated family risks among adolescents.

Keywords Accumulated family risk, Physical activity, Latent growth model, Adolescents, Development trajectory

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Background

Accumulated family risk refers to a combination of adverse family conditions, including low parental education, economic hardship, and lack of parental involvement, all of which have been shown to exert detrimental effects on adolescent development [1, 2]. As research in this field continues to evolve and expand, scholars have identified additional critical factors contributing to family risk, such as mid-course parental divorce, family restructuring, shorter parental education duration, low cultural level, and family economic conditions [3]. In the context of studying adolescent problem behaviors, the persistent and significant impact of accumulated family risk factors has emerged as one of the most pressing challenges in contemporary socialization processes, garnering significant attention from researchers [4]. The study is grounded in ecological systems theory to elucidate the mechanisms through which accumulated family risk influences adolescent physical activity. According to this theoretical framework, individuals are embedded in multiple environmental systems (e.g., family, school, society), which interact dynamically to shape their development outcomes [5]. Within this context, the home environment plays a crucial role in determining adolescents' physical activity patterns, particularly through factors such as parental support and economic conditions [6].

However, recent international research has highlighted significant cross-cultural differences in the manifestation and impact of adolescent accumulated family risk [7]. These differences are often associated with variations in cultural backgrounds and cognitive perceptions of external and internal environments and cultural background. For instance, individuals in cultures that emphasize individualism tend to prioritize personal autonomy and self-expression, often viewing disparities in family structure, economic conditions, and psychological cognition as outcomes of individual choice rather than sources of negative psychological consequences [8]. In contrast, individuals in collectivist cultures perceive the internal environment as interdependent with external social contexts, emphasizing harmony and mutual dependence [9]. In such settings, an incomplete family structure or economic disparity is more likely to be perceived as detrimental to adolescents' physical and mental health. Existing research supports this perspective. For example, studies in central and western regions of China have shown that poor family economic conditions and low parental education levels can exacerbate family risks, leading to issues such as disrupted intergenerational education transmission, increased depression and anxiety, and social rejection by peers [10–13]. Furthermore, scholars have employed latent profile analysis to examine variations in the levels and demographic weighting of accumulated family risk [14]. These studies reveal significant differences in the association between accumulated family risk and adolescent problem behaviors across cultural and demographic contexts, underscoring the role of cultural cognition in shaping these outcomes.

The rise in adolescent problem behaviors due to accumulated family risk has become a critical issue in school and family education. Scholars are increasingly investigating whether protective factors, such as home physical activity, can mitigate these risks. Home physical activity, defined as any form of exercise or movement-based activity performed within the family setting [2], has been theorized to influence family risk through three mechanisms: (1) Enhancing parent–child relationships: Shared physical activities foster positive interactions, improving emotional bonds and communication within the family [15]. (2) Reducing stress and psychological burden: Physical activity has been shown to alleviate stress and anxiety, which are prevalent in families facing economic difficulties or low parental involvement [16]. (3) Promoting social adaptability and self-confidence: Adolescents who engage in regular physical activity develop stronger social skills and resilience, enabling them to cope more effectively with family adversities [17]. These mechanisms suggest that home physical activity not only benefits individual well-being but also contributing to stabilizing family environments. By integrating physical activity into daily routines, families can create a structured and supportive atmosphere, thereby reducing the negative impact of accumulated family risk. This aligns with ecological systems theory, which emphasizes the interplay between individual behavior and environmental influences [18]. Existing research indicates that home physical activity plays a significant role in promoting family harmony and reducing accumulated family risk. However, the context in which adolescents live significantly influences their physical activity levels. For instance, adolescents in urban environments often face greater academic pressure and fewer opportunities for outdoor exercise, whereas those in rural areas may encounter greater socioeconomic disadvantages, leading to higher cumulative family risk [19]. Moreover, as adolescents age, their physical activity levels typically decline due to increased academic pressures, shifting interests, and changes in social engagement patterns. Simultaneously, studies indicate that the impact of family cumulative risk on adolescents may vary across different age groups, with older adolescents experiencing faster growth rates of cumulative risk due to increasing responsibilities and psychological stress [20].

In response to the issue of accumulated family risk, researchers argue that a supportive and interactive home environment is crucial for adolescent well-being [21].

According to the Ecological Systems Theory, a structured and engaging home environment can promote physical activity, which in turn enhances social adaptability and psychological resilience [22]. However, the relationship between accumulated family risk and home physical activity is complex and may vary among different adolescent groups [18]. For instance, highly sensitive adolescents may be more affected by family environments, showing a strong negative correlation between family risk and physical activity levels [23]. In families with higher accumulated risk, the lack of parent–child interaction and communication barriers may further limit opportunities for shared physical activities, leading to a decline in physical activity engagement [24]. These findings underscore the need for tailored interventions consider the varying degrees of sensitivity among adolescents and the unique challenges posed by different family environments [25].

Previous studies have often treated accumulated family risk and physical activity as parallel constructs, making only one-way causal arguments. Some researchers have used physical activity as an outcome variable to assess the impact of accumulated family risk, arguing that persistent family risk exacerbates parent–child conflicts, leading to alienation, reduced social adaptation, and declines in physical activity [26]. Others have considered home physical activity as a predictive variable of accumulated family risk [27]. However, existing research has primarily focused on baseline levels and conducted analyses across only two time points, lacking exploration of the dynamic developmental trajectories of adolescent accumulated family risk and physical activity. Consequently, there is a lack of dialectical analysis of developmental trajectories, and the correlation and trends between these variables have not been thoroughly examined from a dynamic development perspective.

Based on the Ecological Systems Theory, this study examines how accumulated family risk influences adolescents' physical activity over time [28]. The theory posits that external factors, such as family economic conditions and parental involvement, shape youth behaviors through environmental interactions [29]. This study aims to determine whether home physical activity can mitigate the negative impact of these risk factors [30]. These are critical issues that urgently need to be resolved [31]. Methodology is an essential tool for solving real-world problems, and it has become a consensus among scholars in the humanities and social sciences to use statistical modeling to clarify the root causes of issues [32].

To address these gaps, this study employs latent growth modeling (LGM) [33] to clarify the longitudinal development trajectories and interaction mechanisms of the variables under investigation through observation at three-time points [34]. Drawing on developmental psychology theories, the study spans multiple educational stages (late childhood, adolescence, early adulthood) to examine long-term developmental trajectories [35]. Prior research indicates that family risk factors and physical activity patterns evolve over time, necessitating a broader age range to capture these dynamics [36]. Additionally, scholars emphasize that cognitive and behavioral development varies by age, supporting the inclusion of participants aged 10–22 years [37]. This theoretical rationale underpins our decision to expand the sample range, ensuring a comprehensive analysis of accumulated family risk and adolescent physical activity [38]. By refining our methodology, we align with best practices in longitudinal studies and improve the validity of our findings [39].

This study examines the bidirectional relationship between accumulated family risk and adolescent home physical activity. Using a latent growth model, we analyze three time points to capture the dynamic interaction between these variables. The study proposes the following hypotheses: (1) Accumulated family risk negatively correlates with home physical activity over time. (2) Higher initial levels of home physical activity predict slower increases in accumulated family risk, suggesting a protective effect. (3) Higher initial levels of accumulated family risk predict lower growth rates in adolescent physical activity, indicating a long-term inhibitory effect.

Research methods

Participants

The study employed a stratified random cluster sampling method to ensure a representative and diverse sample. The target population encompassed students across multiple educational stages, including upper elementary school (Grades 5–6), middle school (Grades 7–9), high school (Grades 10–12), and university freshmen. To capture geographical and educational diversity, four cities were selected: Chengdu (Sichuan), Guangzhou (Guangdong), Qinhuangdao (Hebei), and Beijing. One school per city was randomly chosen for data collection, with selection criteria emphasizing public status and balanced student demographic composition to enhance sample representativeness. A total of 15 classes participated, yielding an initial sample of 682 students (M age = 13.48, SD age = 0.67), including 294 males and 388 females. Age was measured as a continuous variable, allowing participants to report their exact age (e.g., 12.5 years). This approach improves the precision of age distribution representation and aligns with the analytical framework of the study. Baseline demographic characteristics across the four cities were compared, confirming no significant differences in socio-economic background ($P > 0.05$),

thereby ensuring sample homogeneity across regions [40].

Three follow-up assessments were conducted at three-month intervals to track longitudinal changes. Informed consent was obtained from both participants and their parents to ensure ethical compliance. During the second and third surveys, attrition occurred due to reasons such as student transfers, sickness, leave of absence, and other conflicting activities, resulting in attrition rates of 5.44% and 8.76%, respectively. To assess the nature of missing data, the MCAR (Missing Completely at Random) test was employed, confirming a random missing pattern ($P > 0.05$) [41]. Despite the relatively low missing data rate, robust statistical techniques were applied to address missing responses. Full Information Maximum Likelihood (FIML) and Multiple Imputation (MI) were utilized to preserve statistical power and minimize bias [42]. MI was particularly advantageous in this longitudinal study, as it prevents the loss of valuable information associated with listwise deletion. To validate the robustness of the imputation method, a sensitivity analysis was conducted by comparing results obtained with and without imputation [43]. Additionally, a parallel complete case analysis (CCA) was performed as a supplementary sensitivity test. Results demonstrated that key path coefficients (β values) remained highly consistent across methods, with deviations of less than 5%. Furthermore, model fit indices were nearly identical (MI: CFI = 0.94, RMSEA = 0.05; CCA: CFI = 0.93, RMSEA = 0.06), confirming that the choice of missing data handling methods did not significantly influence the core findings. To ensure the integrity and reliability of the data, several quality control measures were implemented. Incomplete responses (those with less than 50% completion) were removed from the dataset. Outliers, defined as responses exceeding three standard deviations from the mean, were excluded to minimize the influence of extreme values. Response times were analyzed to identify and exclude potential careless responses, and participants with excessively short completion times were also removed [44].

Research tools

Accumulated family risk

The Accumulated Family Risk Index was assessedusing six key risk factors, which are widely recognized in cumulative risk frameworks [45]. These six sub-dimensions are described below:

Parental Education Level: Following Buehler's method [46], parental education levels were assessed useing a 7-point Likert scale, where "1" represents illiteracy and "7" represents postgraduate level and above. If both parents have an education level lower than high school, the respondent was classified at risk (coded as "1"); otherwise, risk was considered absent (coded as "0").

Family Type: Based on Dong Qi's scale [47], participants were asked, "Who do you live with at home?" (multiple-choice). Respondents who did not live with both biological parents were classified as at risk (coded as "1"); otherwise, risk was considered absent (coded as "0").

Economic Pressure: Wang Jianping's Economic Pressure Questionnaire [48] was used to assess financial strain. This measure includes four items rated on a 5-point Likert scale. Respondents in the highest three quartiles of financial stress were classified at risk (coded as "1"); others were coded as "0".

Parental Interaction Participation: Using Evans and Cassell's scale [49], this measure evaluated the average weekly hours of parent–child interaction (games, sports, conversations) on a 4-point scale: "1–3 h" (1), "3–5 h" (2), "5–7 h" (3), "over 7 h" (4). Respondents in the bottom quartile were classified at risk (coded as "1"); others were coded as "0".

Family Care Degree: This measure evaluated five dimensions of family care—intimacy, synthesis, maturity, emotional degree, and adaptability—on a 0–2 scale: "almost rarely" (0), "sometimes like this" (1), and "often like this" (2). Respondents scoring 4 or less were classified at risk (coded as "1"); others were coded as "0".

Parenting Style: Parker's Parenting Style Questionnaire [50] was used to evaluate parenting behavior across three dimensions: care, control, and encouragement of autonomy. The 23-item scale was administered separately for fathers and mothers, with each item rated on a 4-point Likert scale (0 = very inconsistent, 3 = very consistent). The overall Cronbach's alpha coefficients were 0.83 for the father version and 0.86 for the mother version, indicating strong internal consistency. Dimension-specific Cronbach's alpha values further confirmed reliability: for the father version, care (α = 0.85), control (α = 0.76), and encouragement of autonomy (α = 0.79); for the mother version, care (α = 0.87), control (α = 0.78), and encouragement of autonomy (α = 0.81). Respondents scoring below the mean standard for their respective versions were classified as at risk (coded as "1"); those scoring above the mean were considered not at risk (coded as "0").

The accumulated family risk index was computed as the sum of these six sub-scales, using a dichotomous scoring method (0 = no risk, 1 = at risk). This resulted in a cumulative risk score ranging from 0 to 6.

To assess the robustness of the dichotomization approach, a sensitivity analysis was conducted by comparing the results of dichotomous and continuous scoring methods [51]. The Cronbach's alpha coefficient for the total scale was 0.82, indicating strong reliability. To further validate the dichotomization, a median split was performed and compared with alternative methods such as z-score standardization. Results demonstrated consistency across methods, supporting the use of dichotomization. Additionally, prior research has established the effectiveness of binary risk scoring in developmental psychology research, particularly for assessing cumulative effects across multiple risk domains [52].

Home physical activity

The Home Physical Activity Index was assessed using the International Physical Activity Questionnaire (short version) (IPAQ-SF) developed by Craig et al. [53]. This questionnaire consists of seven items designed to measure the frequency and duration of physical activity over the past seven days. The IPAQ-SF classifies physical activity into three categories: (1) Walking: This category includes light-intensity activities performed for transportation or leisure; (2) Moderate-Intensity Activity: This encompasses activities such as brisk walking, cycling, or recreational sports; (3) High-Intensity Activity: This refers to activities requiring substantial physical effort, such as running, aerobics, or competitive sports. Each type of activity was assigned a metabolic equivalent (MET) value based on international IPAQ-SF scoring guidelines, ensuring standardized measurement across different activity levels. The total physical activity score was calculated by summing the MET-minutes per week for each category, providing an overall estimate of the respondent's physical activity level. To evaluate the reliability of the scale, the Cronbach's alpha coefficient for the IPAQ-SF in this study was computed and found to be 0.81, indicating good internal consistency and measurement reliability. This robust reliability underscores the suitability of the IPAQ-SF for assessing home physical activity levels in the context of this study.

Research procedure

The study was conducted in three waves over nine months (Wave 1: March 2022, Wave 2: June 2022, Wave 3: September 2022), with each wave lasting for two weeks. Prior to data collection, all participants attended a 20-min standardized briefing session, during which they were informed about the study objectives, confidentiality measures, and voluntary participation. Surveys were administered in Mandarin, the native language of all participants, using the online platform Questionnaire Star. Participants completed the survey in a designated 15-min session in class, utilizing school computers or personal mobile devices. To accommodate individual needs, participants were allowed to pause and resume the survey if necessary. To ensure data integrity and minimize missing responses, researchers closely monitored the data collection process, conducted logic validation, and analyzed response times. Participants who missed a wave due to absence were given the opportunity to complete the survey within one week. All collected data were securely stored and anonymized for analysis. These measures were implemented to maintain consistency between survey items and sample characteristics, thereby enhancing the reliability and validity of the study findings.

Statistical methods

Data analysis was conducted using SPSS 26.0 and Mplus 24.0. Descriptive statistics were used to summarize sample characteristics. Reliability analysis, measured using Cronbach's alpha, was conducted to assess the internal consistency of the scales [54]. Pearson correlation analysis was used to examine the relationships between key variables [55]. To explore changes in family risk and physical activity trajectories over time, Latent Growth Modeling (LGM) was applied [56]. Model fit indices (CFI, TLI, RMSEA, SRMR) were used to evaluate LGM models [57]. Multi-group analysis was performed to test for potential gender differences in developmental trajectories [58]. Additionally, the parallel latent growth model was used, with regression equations established for accumulated family risk and physical activity, to observe the overall development trends of the model [59].

Ethic

This study adhered to ethical research standards and received approval from the Research Ethics Committee of Leshan Normal University (Approval No.: LSEDU: 20220602). Written informed consent was obtained from all participants and their guardians prior to participation. Participants were fully informed about the voluntary nature of their involvement, the anonymity of their responses, and the confidentiality of the data collected. They were assured that they could withdraw from the study at any time without penalty. Schools involved in the study received a summary report of general findings, but no individual data was shared to protect participant privacy. No identifying information was collected during the survey process. The study complied with the ethical principles outlined in the Helsinki Declaration and adhered to local research regulations. Participants who experienced any discomfort during the study were provided with access to school counselors for support.

Results

Descriptive statistics

The matrix of correlation coefficients between cumulative risk at home and physical activity at home for adolescents on the three pre- and post-measurements is shown in Table 1. The main effect coefficients for gender, analysed by repeated measures ANOVA (MANOVA) test, were F = 32.842, $p < 0.01$, WILKS' Lambda = 0.92,η2 = 0.08, the main effect coefficient for time was F = 0.842, $p > 0.05$, WILKS' Lambda = 0.98, the coefficient of the interaction term between measurement time and gender was F = 0.46, $p > 0.05$, WILKS' Lambda = 0.98, the one-way ANOVA test further showed that cumulative risk in the household was higher for boys than for girls, while the matrix of correlation coefficients showed that the cumulative risk was negatively and significantly associated with home-based physical activity in all time periods, as shown in Table 1.

Unconditional latent growth model

The unconditional latent growth model is primarily used to examine the developmental trajectory of variables, focusing on the individual and group changes over time [35]. The slope and intercept terms represent the growth rate and initial level of the variables, respectively [36]. Researchers often use Mplus 24.0 to explore the developmental trajectory and estimate related parameters for different unconditional latent growth models.

First, the developmental trajectory of cumulative family risk was examined using an unconditional latent growth model. Rather than assuming a unidirectional effect of the intercept on the slope, we modeled their relationship as a covariance structure, following the recommendations of Grimm K J [57]. This approach provides a more flexible representation of individual differences in growth patterns. The model demonstrated good fit to the data, with $\chi^2/df = 0.62$, RMSEA = 0.048, CFI = 0.986, TLI = 0.979, and SRMR = 0.032, in accordance with the fit indices recommended by Hu & Bentler [60]. The intercept term, representing the initial level of cumulative family risk, was 2.07 ($P < 0.01$), indicating a moderate baseline level of risk. The slope term ($\beta = -0.02$, $P = 0.34$) suggests that cumulative family risk remains relatively stable across the three time periods. Both the intercept ($\sigma^2 = 0.04$, $P < 0.01$) and slope ($\sigma^2 = 0.02$, $P < 0.01$) exhibited significant variance, highlighting individual differences in initial risk levels and growth rates. Notably, a significant negative covariance was observed between the intercept and slope ($\sigma^2 = -0.02$, $P < 0.01$), indicating that individuals with higher initial risk levels tend to experience a slower increase in risk over time. This finding aligns with prior research on developmental trajectories [58] and suggests a potential self-regulating mechanism in the progression of cumulative family risk. For further details, please refer to Fig. 1.

Next, the developmental trajectory of home-based physical activity in adolescents was examined using an unconditional latent growth model. The goodness-of-fit indices for the model are as follows: $x^2/df = 0.62$. The intercept term has an initial level of 0, which is not significantly different from zero ($P = 0.82$). The physical activity remains relatively stable between the three consecutive measurements ($\beta = -0.02$, $P = 0.62$). The intercept term ($\sigma^2 = 0.06$, $P < 0.01$) is significantly greater than zero, indicating individual differences in the initial level of physical activity. The slope ($\sigma^2 = 0.02$, $P < 0.01$) also has a variability coefficient greater than zero, suggesting individual differences in the growth rate of physical activity. There is a significant positive correlation between the intercept term and the slope ($\sigma^2 = 0.03$, $P < 0.01$), indicating that individuals with higher initial levels have a faster subsequent growth rate. Please refer to Fig. 2 for more details.

To further analyze the differences between the latent variables, a multiple-group analysis (MGA) was conducted, and measurement invariance was tested to assess whether the parallel growth model exhibited consistent structural properties across gender, age, and recruitment site. Specifically, configural, metric, and scalar invariance models were compared using the Chi-square difference test ($\Delta\chi^2$), where non-significant results indicate that the model structure holds equally across groups [61].

Following established methodologies in latent growth modeling, a parallel growth model was constructed

Table 1 Correlation coefficient matrix of family cumulative risk and home physical activity

	Boys	Girls	1	2	3	4	5	6
1.T1 CR	.29 ± .87	.20 ± .93	1					
2.T2 CR	.32 ± .91	.21 ± .94	.35**	1				
3.T3 CR	.34 ± .76	.21 ± .88	.35**	.38**	1			
4.T1 PA	.38 ± .86	.34 ± .86	-26**	-.13**	-.15**	1		
5.T2 PA	.39 ± .92	.33 ± .87	-.16**	-.24**	-.16**	.27**	1	
6.T3 PA	.41 ± .93	.35 ± .90	-.16**	-.17**	-.28**	.24**	.27**	1

Variables are standardized scores, * indicates $P < 0.05$, ** indicates $P < 0.01$, and *** indicates $P < 0.001$, as follows

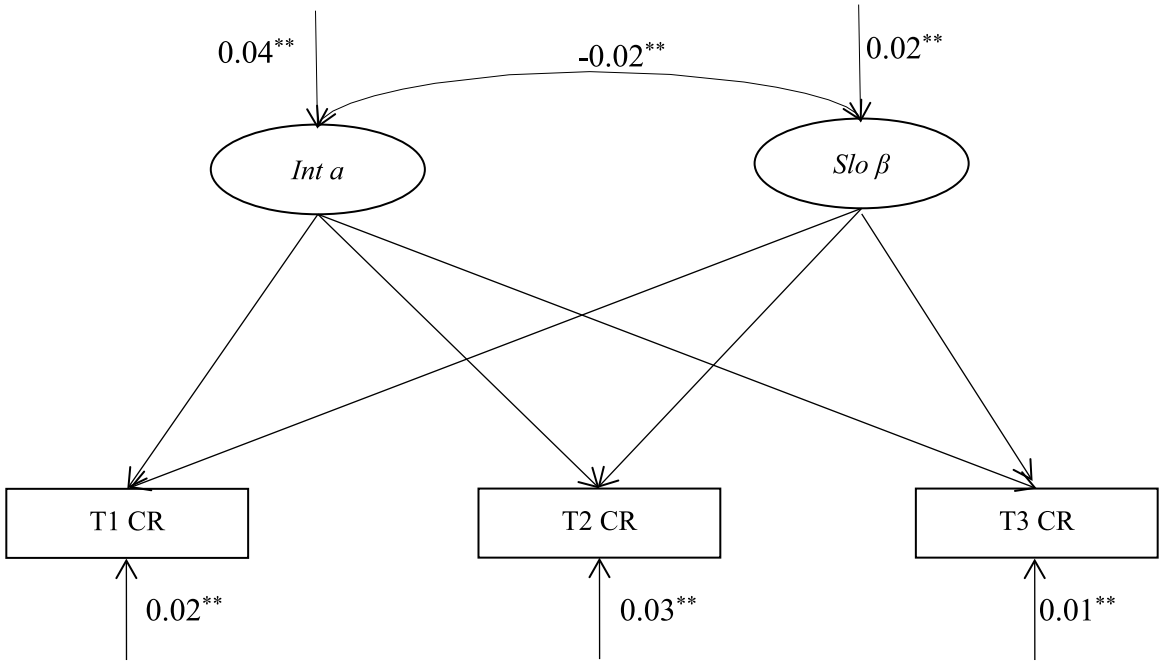

Fig. 1 Developmental trajectory of cumulative family risk

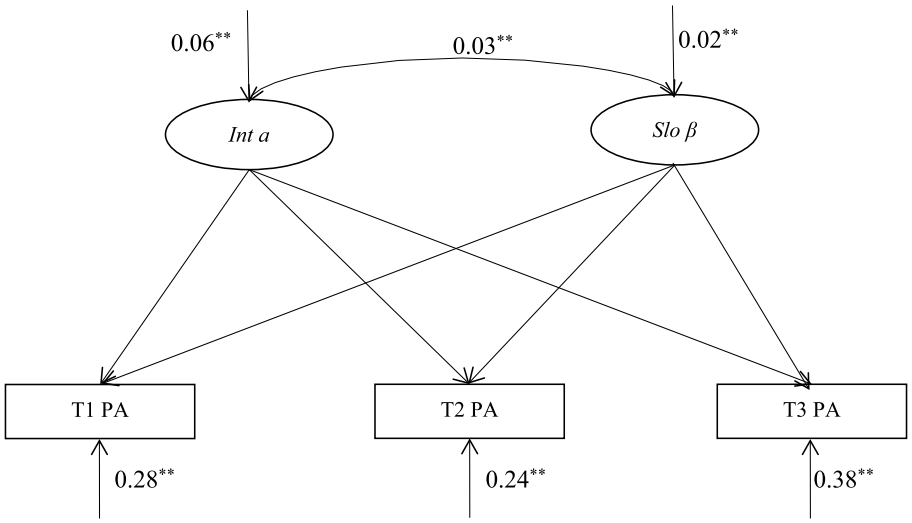

Fig. 2 Developmental trajectory of home-based physical activity in adolescents

to assess the trajectory of cumulative household risk and home-based physical activity. To improve model specification and reduce estimation bias, a stepwise model-building approach was employed, sequentially incorporating additional covariates. To minimize potential confounding effects, control variables were expanded beyond gender to include age, recruitment site, and educational stage. Age was treated as a continuous variable, while recruitment site and educational stage were included as categorical variables using dummy coding.

As illustrated in Fig. 3, the model demonstrated an adequate fit to the data, with χ^2/df = 2.07, RMSEA = 0.05, CFI = 0.94, TLI = 0.92, and SRMR = 0.056. These indices indicate that the model fits the data well, as χ^2/df values below 3 suggest an acceptable model fit [59], and RMSEA values below 0.06 indicate a close model fit [62]. Additionally, CFI

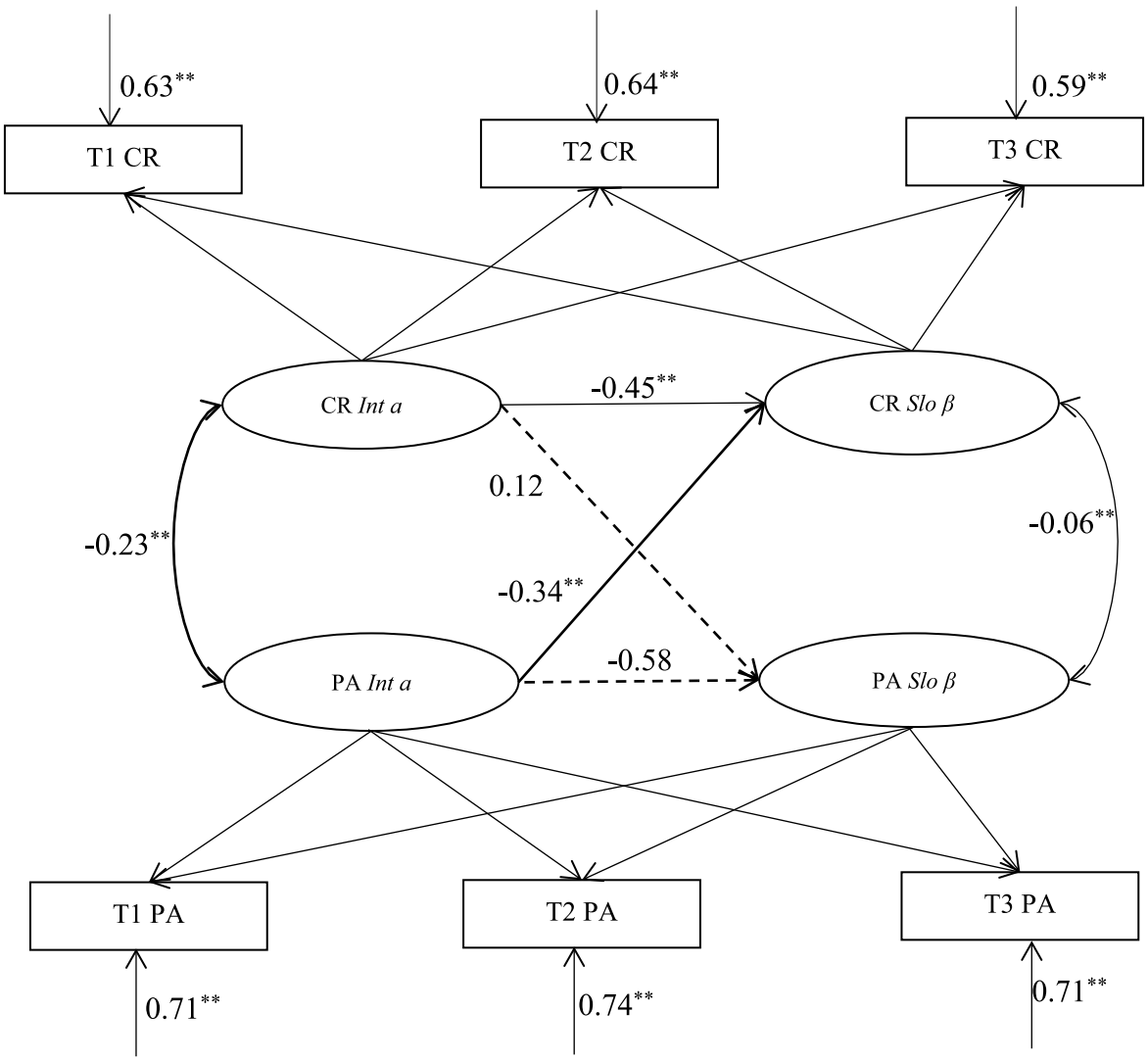

Fig. 3 Parallel latent growth model of cumulative family risk and home-based physical activity in adolescents. Note: Adolescent gender has been controlled

and TLI values above 0.90 are considered indicators of a well-fitting model. To further validate the robustness of the model, we conducted a bootstrapping procedure (1,000 resamples) to assess parameter stability and confidence intervals. These results confirm the structural stability of the parallel latent growth model and its applicability in analyzing the longitudinal relationship between cumulative household risk and home-based physical activity. Moreover, a sensitivity analysis was conducted by comparing results from multiple imputation (MI) and complete case analysis (CCA) [58]. The findings remained highly consistent, with key path coefficients differing by less than 5%, confirming that the choice of missing data handling approach did not significantly influence the core conclusions.

After incorporating additional covariates, the analysis of cumulative household risk and home-based physical activity was refined. The results indicated that gender significantly influenced both cumulative household risk ($\beta = 0.15$, $P < 0.05$) and home-based physical activity ($\beta = -0.22$, $P < 0.01$), with females experiencing higher initial cumulative risk but lower physical activity levels than males. Age significantly predicted the rate of increase in cumulative risk ($\beta = 0.18$, $P < 0.05$), suggesting that older adolescents face greater family-related stressors over time.

However, age did not significantly affect the initial level or growth rate of home-based physical activity, implying that while cumulative family risk increases with age, adolescents' engagement in physical activity

remains relatively stable. Additionally, recruitment site had a notable impact on cumulative risk levels ($\beta = 0.21$, $P < 0.05$), with urban adolescents exhibiting higher cumulative risk, likely due to increased academic pressure and fewer opportunities for physical activity [44].

The results confirmed that the overall model fit remained robust, reinforcing the structural validity of the parallel latent growth model. To enhance parameter estimation accuracy and accommodate potential non-normality in observed variables, we employed Bayesian estimation instead of maximum likelihood estimation. Bayesian methods provide more stable parameter estimates, particularly in studies with relatively small sample sizes [63].

Notably, while cumulative household risk and initial levels of home-based physical activity exhibited significant cross-sectional effects, neither variable significantly influenced the rate of change in physical activity over time. This suggests that while cumulative risk may inhibit initial engagement in physical activity, its long-term trajectory is not directly impacted by the accumulation of family risk factors.

These findings, illustrated in Fig. 3, underscore the complex interplay between adolescent home-based physical activity and cumulative household risk, highlighting the need for targeted interventions that address demographic disparities in risk exposure and physical activity engagement.

Discussion

Gender differences and reciprocal predictive relationships

This study identified significant gender differences in home-based physical activity among adolescents, with boys having higher frequency and levels of home-based physical activity compared to girls. This finding is consistent with previous research [64, 65], suggesting that girls may prefer engaging in sedentary activities, such as listening to music, reading extracurricular materials, and participating in other non-physical activities. These differences may reflect variations in personality traits, preferences, and socialization processes between genders.

Furthermore, this study revealed gender differences in cumulative family risk, which aligns with previous research [66]. According to the Ecological Systems Theory, adolescent development is shaped by the interaction between individual characteristics and environmental factors [67]. Prior studies suggests that gender differences in coping strategies may stem from socialization processes rather than inherent traits [68]. For instance, girls often experience distinct parental expectations, which can influence their engagement in home-based physical activity [69] Additionally, adolescents with lower perceived parental support may exhibit reduced resilience, potentially explaining the observed gender differences in cumulative family risk [70]. These factors can contribute to social withdrawal, difficulties in empathy and perception, and the formation of personality and behaviors [71], ultimately shaping gender-specific perceptions of cumulative family risk.

Overall, these findings underscore significant gender differences in home-based physical activity and cumulative family risk among adolescents. The results align with existing literature and highlight the influence of personality traits, preferences, and external perceptions on these differences. Understanding these gender-specific dynamics is crucial for designing targeted interventions and providing support tailored to the unique needs and challenges faced by boys and girls during adolescence.

The study confirmed that higher levels of accumulated family risk correlate with reduced home-based physical activity, supporting previous findings [72]. However, it is also essential to consider that adolescents with higher levels of home-based physical activity may already come from families with lower cumulative risk. This relationship can be explained through three primary mechanisms:(1) Family stress and conflict: Families experiencing high accumulated risk often face greater financial and emotional stress, which can significantly reduce their capacity to engage in shared activities such as physical exercise [73]. The psychological burden within these families may also lead to communication barriers, further limiting opportunities for positive parent–child interactions through physical activity [74]. (2) Lack of parental involvement: Parents in high-risk families often work longer hours or struggle with mental health challenges, resulting in reduced encouragement and support for adolescent physical activity [75]. Consequently, adolescents in these families are more likely to engage in fewer home-based physical activities, reinforcing a cycle of low physical engagement. (3) Socioeconomic and educational advantages: Families with higher parental education levels and greater financial stability may provide more opportunities for structured physical activities, leading to increased adolescent engagement in home-based physical activity [76]. More educated parents tend to have greater awareness of the benefits of physical activity and may actively encourage their children to participate in regular exercise [77]. Additionally, financially stable families have more resources to support physical activities, such as providing sports equipment, enrolling children in extracurricular sports programs, or having access to safer recreational spaces [78].

The study incorporated data from four major cities—Chengdu, Guangzhou, Qinhuangdao, and Beijing—representing diverse socio-economic and educational environments. Prior research indicates that urban

adolescents tend to experience greater academic pressure and have fewer opportunities for physical activity, whereas those in rural or less developed areas may face higher economic instability, exacerbating cumulative family risk [79]. These regional disparities could contribute to variations in home-based physical activity and family risk levels, suggesting that future studies should employ multi-level modeling approaches to account for environmental influences [80].

The interaction between cumulative family risk and home-based physical activity is bidirectional. Adolescents from families with higher cumulative risk not only face barriers to engaging in physical activity but also experience a lack of motivation and initiative due to negative emotional states and financial constraints [81]. These factors significantly weaken adolescents' ability to actively participate in physical activities, limiting their autonomy in engaging in physical exercise. Conversely, adolescents from families with lower cumulative risk may benefit from greater parental support, structured physical activities, and a more stable home environment, which collectively enhance their likelihood of engaging in home-based physical activity [82].

Longitudinal data further confirm a significant negative correlation between cumulative family risk and home-based physical activity [83], indicating that these variables dynamically influence each other over time. This highlights the need for interventions that simultaneously address family risk factors and promote physical activity engagement. Future research should incorporate controls for socio-economic factors, parental education, and peer influences to better elucidate the causal mechanisms underlying this relationship.

The developmental trajectories and dynamic relationship between cumulative family risk and home-based physical activity in adolescents

To examine the interaction and trajectory of latent variables in more detail, a parallel latent growth model was employed. The results revealed that the initial level of home-based physical activity significantly predicted the growth rate of cumulative family risk in a negative direction, indicating a compensatory buffering effect. This finding aligns with the Ecological Systems Theory, which posits that adolescent behavior is shaped by interactions between individual, family, and societal factors [84]. Home-based physical activity may serve as a protective factor by fostering positive parent–child interactions, which in turn reduce stress and mitigate cumulative family risk [85]. Additionally, social-emotional need theory suggests that engaging in physical activity with family members can strengthen emotional bonds and enhance resilience, further buffering against the adverse effects of accumulated family risk [86].

Firstly, from the perspective of the family as a unit, Chinese culture emphasizes that material conditions determine the superstructure. In general, groups with higher levels of material development are more likely to have better spiritual and cultural lives. The material foundation of the family determines the possibility of parent–child participation in projects [87]. The educational attainment of parents may influence the cognitive development of their children [88]. These factors are important determinants of cumulative family risk. In the process of socialization norms, schools often require students to follow rules and agreements, which can bring stress to students from different levels of cumulative family risk, leading to individual discomfort and emotional resistance [89]. This demonstrates the role of school education in cumulative family risk, highlighting the importance of changing individuals' cognitive sensitivity and social support. In the context of traditional Chinese culture, people tend to overly focus on their children's education and growth, especially in cultural education and health. Academic performance is a key and central concern for schools, parents, and children. However, school physical activities and family physical activities can promote interpersonal communication skills and improve social adaptation skills [90]. They can also slow down the growth rate of cumulative family risk. As a result, individuals who excel academically and engage in regular physical exercise are more likely to adapt to society and integrate into the family unit environment [91].

Unlike previous studies, this study expanded the original baseline research to three time points, conducting a longitudinal examination of growth trajectories. It aimed to further explore the interactive mechanisms and developmental rates among the research variables. The results further support the significance of home-based physical activity in parent–child interactions [92]. Due to the deeply ingrained traditional Chinese family concept of "excellence in learning leads to success," individuals who are healthy and academically successful are more likely to be accepted and favored by parents, teachers, and peers [93]. They are also more likely to obtain excellent interpersonal relationships and resources, which can restrain and mitigate the occurrence of internal and external behavioral issues in adolescents.

Furthermore, from the perspective of developmental stages, adolescents are more concerned about the evaluations of teachers and parents regarding their academic performance and behavior [94]. These evaluations represent key focal points of social attention and expectations. The results of previous studies have shown a strong negative correlation between cumulative family risk and

participation in physical exercise among adolescents. This correlation may be related to the cognitive abilities and emotion regulation strategies of children and adolescents [95], or it may be caused by cognitive biases in the recognition and acceptance of the value of physical exercise. Due to their cognitive immaturity, adolescents rely on the ideas and value judgments of their parents and teachers, which can lead to misjudgments of the overall impression of the family due to academic performance, physical exercise, and externalizing problems [96]. As they grow older and their academic knowledge expands, even if adolescents have a more comprehensive understanding of home-based physical exercise, they may also experience issues such as attentional difficulties and decreased focus. This can result in a decline in perceived support and emotional nurturing from family members, leading to the accumulation and blockage of cumulative family risk. It becomes challenging to form positive resolutions, which in turn affects the motivation to sustain engagement in home-based physical exercise [96]. Therefore, it can be argued that individuals who have higher levels of participation in physical exercise tend to have lower perception of cumulative family risk, and the influence of risk is relatively short-lived.

Moreover, from a social-ecological perspective, an ideal natural environment is most conducive to individual growth and development. Academic achievement and physical exercise participation are also essential components in the development of adolescents' social adaptation skills. They play important roles in the process of environmental adjustment and adaptation. As students advance through different educational stages and their cognitive abilities improve, those who have a high level of engagement in physical exercise in the initial stages are more likely to integrate into peer groups, interact with teachers and parents, and enhance their subjective well-being and social adaptation skills. This demonstrates the mitigating effect of physical exercise on cumulative family risk [97].

However, contrary to the research hypothesis, the data shows that the initial level of cumulative family risk does not significantly predict the growth rate of home-based physical exercise. Previous researchers have suggested that cumulative family risk can significantly predict the level of participation in home-based physical exercise [98]. This indicates that in the context of Chinese culture and educational involvement, educational achievements are influenced by previous performance, creating a chasing effect that leads to the long-term influence of parental involvement on home-based physical exercise activities. On the other hand, the initial level of cumulative family risk does not directly impact the growth rate of home-based physical exercise in adolescents. It may instead affect the level of physical exercise participation during the same period, thereby exerting a restraining and mitigating effect on the overall cumulative family risk.

Limitations and prospects

Different from previous scholars, this study employed a longitudinal analysis using multiple time points to address the challenge of comparing individual and group differences [99]. This approach allows for the observation of latent variable trajectories, growth trends, and the interplay between variables. By examining historical data across three time periods, this study established a parallel latent growth model for cumulative family risk and home-based physical activity among adolescents. The findings confirmed the protective role of home-based physical activity in the context of cumulative family risk, providing insights and evidence for further understanding the dynamic relationship between these factors. The study also offers practical and theoretical implications for educators and caregivers. For example, to enhance adolescents' social adaptation, subjective well-being, psychological health, and academic performance, and to mitigate cumulative family risk, focusing on parent–child interactive home-based physical activity programs can effectively reduce problematic behaviors in adolescents.

This study, while providing valuable insights, is not without limitations. First, although it focused on examining the dynamic relationship between cumulative family risk and home-based physical activity among adolescents, several potential confounding factors were not accounted for, such as parental employment status, household income, and peer influence. Future studies should incorporate a broader range of socio-economic and psychosocial variables to provide a more comprehensive understanding of adolescent development. Second, while age, recruitment site, and educational stage were controlled for, unmeasured cultural or environmental factors may still influence the relationship between cumulative family risk and physical activity. Future research should consider cross-cultural comparisons to explore how different socio-cultural contexts shape these developmental trajectories. Finally, the study's longitudinal design was constrained by practical limitations, including school accessibility and research funding, resulting in data collection across only three time points. To enhance the robustness of longitudinal analyses, future research could expand to include 4–6 time points, adopt mixed-method approaches, and investigate potential nonlinear trends in the development of cumulative family risk.

Conclusion

Cumulative family risk and home-based physical activity among adolescents show relatively stable development across three time periods, and there is a significant negative correlation between cumulative family risk and home-based physical activity in all three periods. (2) The initial level of home-based physical activity negatively predicts the growth rate of cumulative family risk, while the initial level of cumulative family risk negatively predicts its own growth rate. These findings suggest that home-based physical activity serves as a protective factor in the development of cumulative family risk, with higher initial levels of cumulative family risk associated with slower subsequent growth rates.

It is also plausible that adolescents with higher engagement in home-based physical activity may already originate from families with lower cumulative risk, where higher parental education levels and greater financial stability provide more opportunities for structured physical activities. Future research should account for these factors to disentangle the independent effect of physical activity on cumulative family risk and to better understand the underlying mechanisms driving this relationship.

Supplementary Information

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Supplementary Material 1.

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Not applicable.

Informed consent
Informed consent was obtained from all participants of this study. Written informed consent was also provided by the parents or legal guardians of the participants.

Note
In the data analysis, in order to simplify tables and charts and to facilitate reading by readers and reviewers, Cr in this study was the cumulative risk for the family, PA for physical activity participation, Int for intercept, and Slo β for slope.

Authors' contributions
JW designed the study, performed the statistical analysis, and contributed to writing the manuscript. WZ also contributed to writing the manuscript. JH, YS, and XZ supervised all aspects of the study's implementation, and reviewed the manuscript. WZang contributed to data collection and study coordination. All authors have read and approved the final manuscript.

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Data availability
The datasets generated and/or analysed during the current study are not publicly available due to ethical issues but are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This manuscript has not been reviewed elsewhere and as a result has not been previously published or accepted for publication. This manuscript has been read and approved by all authors. All methods were performed in accordance with relevant guidelines and regulations. The questionnaire and methodology of this study were approved by the Research Ethics Committee of the School of Physical Education and Sport, Leshan Normal College, prior to data collection. The ethics committee granted approval for the study to proceed as planned, under the approval number.
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Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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