RESEARCH QUARTERLY FOR EXERCISE AND SPORT
https://doi.org/10.1080/02701367.2026.2623652

Routledge
Taylor & Francis Group

Social Network Intervention in Physical Education Classes Through Social Support to Promote Physical Activity and Reduce Screen Time in Adolescents: A Cluster Randomized Controlled Trial

José Petro-Petro [a,b], Carlos Mario Arango-Paternina [a], and Fredy Alonso Patiño-Villada [a]

[a]University of Antioquia; [b]University of Córdoba

ABSTRACT

Physical activity (PA) and screen time (ST) are complex behaviors influenced by social factors such as relationships with family and friends, linked to mechanisms such as social support. This study implemented a segmentation-based social network intervention which is a promising approach to improving health-behaviors in a network. The objective was to determine the effects of a social network intervention through social support from friends and parents on PA and ST among adolescents. A cluster-randomized controlled trial was conducted involving 4 schools, 24 classrooms, with 787 adolescents. A segmentation-based social network intervention was implemented over ten weeks in physical education classes. Two components, ClassI involving friends support and ParentsI involving parents support was included. Follow-up was conducted at week ten post-intervention. A mixed-effects model was used to determine the effectiveness. Network mechanisms of perceived social support from friends most associated with PA and ST were explored. Findings indicated a significant increase of 12.2 daily minutes of PA in the intervention group (95% CI: 1.9 to 22.5, $p = .02$). Main effects suggest sustainability over time. Social support from friends and parents was significant ($p < .001$), and homophily was positively associated with PA ($p < .05$). For ST, a reduction of 56.7 minutes was observed in the intervention group (95% CI: −105.2 to −8.1, $p = .02$). Main effects indicate that the effectiveness for ST was not sustainable over time. Implementing a social support network intervention from friends and parents within physical education classes is effectively increased daily PA and decreased ST among adolescents.

ARTICLE HISTORY
Received 5 June 2025
Accepted 22 January 2026

KEYWORDS
Friend network; participative intervention; social support network; system science

Physical activity (PA) and sedentary behaviors (SB) are highly complex (Pettee Gabriel et al., 2012). Jointly or independently, are associated with the development of risk factors for non-communicable diseases from an early age (Anderson & Durstine, 2019). There is growing concern regarding adolescence, a stage characterized by a low prevalence of compliance with PA recommendations (Cardon & Salmon, 2020; Guthold et al., 2020) and the high prevalence of SB (Arundell et al., 2016), particularly excessive recreational screen time (ST). The protective role of PA in adolescent health is widely recognized, as it reduces the risk of developing non-communicable diseases such as hypertension, metabolic syndrome, and obesity, among others (Janssen & LeBlanc, 2010). Additionally, PA is associated with better mental health, improved executive functions, and higher quality of life (Bidzan-Bluma & Lipowska, 2018; de Greeff et al., 2018; Wu et al., 2017), as well as lower cigarette and alcohol consumption (de Victo et al., 2024). Conversely, excessive ST has been linked to negative physical, mental, and social health outcomes, as well as a decline in health-related quality of life (V. Carson et al., 2016; Fang et al., 2019; Rodriguez-Ayllon et al., 2019).

The World Health Organization (WHO) has set a goal of reducing physical inactivity levels by 15% in both adults and adolescents by 2030, along with decreasing time spent in SB (Bull et al., 2020). One potential strategy to contribute to this goal is integrating schools and physical education classes into interventions targeting these behaviors (Hills et al., 2015). However, a recent review of school-based interventions concluded that their effects on increasing PA and reducing SB time in children and adolescents are small or negligible (Neil-Sztramko et al., 2021). The limited effectiveness of these interventions may stem from an inadequate consideration of the diverse and multidimensional factors influencing health-related behaviors (Hosseini Shokouh et al., 2017).

The socio-ecological model suggests that health behaviors are shaped by multiple levels of influence (McLeroy et al., 1988). One of these is the interpersonal level, which highlights relationships established with family, friends, classmates, and other actors that have a direct impact on PA and SB behaviors (Berkman et al., 2014; Norman et al., 2005; J. F. Sallis et al., 2006). Evidence suggests that low levels of social connection and interaction are associated with risk factors such as heart disease and diabetes mellitus (Abreu et al., 2024), In contrast, strong social interactions can serve as a protective factor for health (Hunter et al., 2019) and have been identified as an independent protective factor against mortality, regardless of age, sex, or baseline health status (Holt-Lunstad et al., 2010). Within these interpersonal relationships with family and

CONTACT José Petro-Petro jose.petrop@udea.edu.co Instituto Universitario de Educación Física, University of Antioquia, Cra 75 N° 65-87 - Block 45, Medellín, Colombia.

friend networks, mechanisms such as influence, social norms, and social support (SS) are developed (de la Haye et al., 2011; Sawka et al., 2013). The SS mechanism has been established as a key determinant of PA behaviors in adolescents (H. Lin et al., 2024; Mendonça et al., 2014; J. F. Sallis et al., 2000), whereas a lack of SS is considered one of the main barriers to PA promotion in children and adolescents (Hu et al., 2021). Although further research and stronger evidence are still needed regarding SB, SS could be a relevant mechanism to consider in interventions (Draper et al., 2015). Therefore, different types of SS, as well as sources such as family and friends, may be promising factors in enhancing the effectiveness of PA and ST behavior interventions among adolescents (Duncan et al., 2005; H. Lin et al., 2024; Mendonça et al., 2014).

School-based interventions for adolescents should prioritize participatory and co-creative approaches, integrating a systemic perspective that actively engages key stakeholders (Cardon & Salmon, 2020). Systems dynamics, which emerged in the 1950's, provides a robust framework for capturing the complexity of interactions and nonlinear relationships between variables, particularly those linked to the social environment and human behavior (Sterman, 2000). Two key tools, social network analysis (SNA) and group model building (GMB) facilitate the understanding of social systems and the dynamics of complex problems (Baugh Littlejohns et al., 2023). Social networks enable the diffusion of behaviors by leveraging the ties and structural properties of connections within the network (H. Lin et al., 2019). These networks properties can be quantified and strategically used to implement network-based interventions aimed at fostering complex behavioral changes within the network (Valente, 2010, 2012). Evidence has shown that network-based interventions can effectively promote health-related behaviors (Hunter et al., 2019) including PA and SB (Petro-Petro et al., 2024). Furthermore, GMB has been recognized as a powerful tool for contextualizing interventions by engaging stakeholders in problem-solving and decision-making processes (S. Gerritsen et al., 2019, 2020; Hovmand, 2014). These tools can be integrated to design successful interventions aimed at promoting healthy behaviors (Hennessy et al., 2020).

Despite this progress, it is still required to further expand research on the effectiveness of interventions based on social networks and their different approaches, to modify PA and ST behaviors, especially in the adolescent population (Hunter et al., 2019). While it is true that SNA allows mapping the social system to identify intervention elements within the network, there is a limited research production that examines the joint relationship between the network structure and the promoted social mechanisms such as social support from friends and family using participatory methods (Baugh Littlejohns et al., 2023). This gap is more evident in the context of PE classes, from which opportunities can be created to co-design interventions by giving participation to adolescents, which is often underutilized. Although it is known that the network of friends and parents, as well as the social support from both sources is a key determinant in the improvement of PA and ST behaviors, the combination of both supports has been little explored, especially integrating the co-design of the activities from participatory tools like GMB. In response to this need, the present study focuses on examining the combination of these elements to deepen the understanding of the social dynamics and their influence on PA and ST behaviors in adolescents.

This study aimed to assess the effectiveness of a social network-based intervention implemented within physical education (PE) classes, using SS as a mechanism to promote PA and reduce ST among school-aged adolescents. Additionally, it sought to explore network parameters that could explain these effects. SNA was applied to deploy the intervention by leveraging adolescents' best friend networks, while GMB was used to engage adolescents in understanding the issue and constructing a causal relationship model related to PA and ST behaviors. This process helped identify key leverage points (Meadows, 2008) which were crucial for maximizing the intervention's impact and ensuring its contextual adaptation.

Material and methods

Study design

A two-arm, cluster-randomized controlled trial (1:1 allocation) was conducted in four public schools in Montería, Colombia, following the guidelines of the Consolidated Standards of Reporting Trials (CONSORT) for this type of study (Moher et al., 2012). Two schools were randomly allocated to the intervention group and two to the control group. The flow diagram is presented in Figure 1. The study protocol is registered and openly available on the Open Science Framework (https://doi.org/10.17605/OSF.IO/W3HKF) and was approved by the Ethics Committee of the University of Antioquia (ACEI 44–2023). Furthermore, the study aligns with the best-practice standards for intervention reporting outlined in the Template for Intervention Description and Replication (TIDieR) framework (Hoffmann et al., 2014).

Participants and sample

Twelve public schools from the southern of Montería, Colombia, were considered for the study. As characteristics of the local context, in this population it has been found that about 25% of adolescents reported a high level of physical activity and about 71% reported spending 4 hours or more per day on screen time (Arango-Paternina et al., 2022). Due to resource limitations, six schools were invited to participate, of which four agreed to participate. These schools predominantly serve students from low-income backgrounds and offer educational services across all grade levels. Furthermore, they have a similar sports infrastructure and the same intensity schedule for PE classes. The school principals were initially contacted via a formal letter explaining the study objectives, followed by a meeting with both the principal and the PE teacher. The sample estimation was based on the study by Sebire et al. (2018) who, in a feasibility study, found a significant effect of 6.09 daily minutes of moderate-to-vigorous physical activity (MVPA) in the intervention group compared to the control group in adolescent girls (95% CI: 1.43–10.76), reporting intraclass correlation coefficients (ICC) for the daily minutes of MVPA between 0.00 and 0.02 (Sebire et al., 2018). Consistent with these findings, this study assumed an ICC of 0.01 for a difference of 10 daily minutes of MVPA

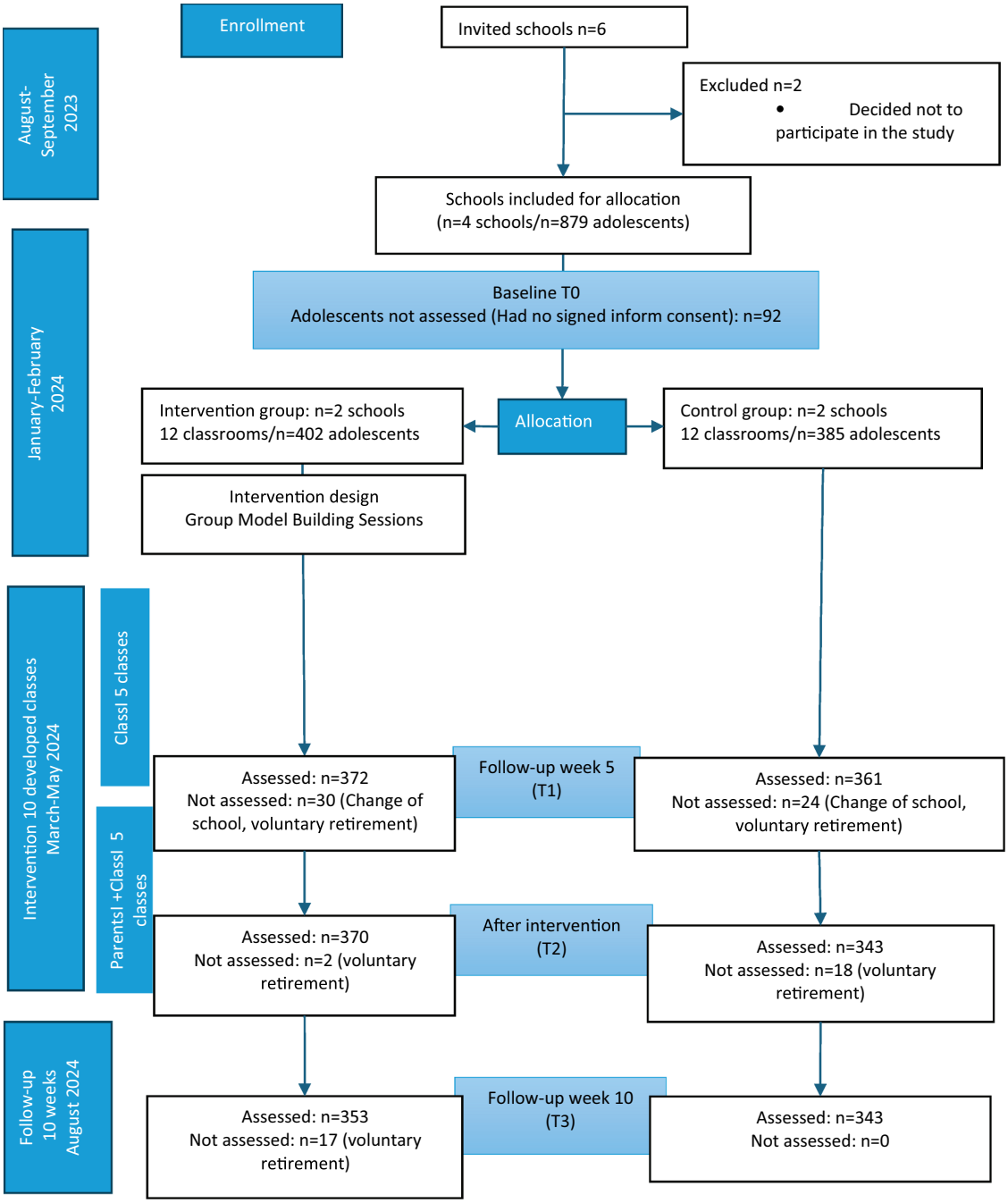


Figure 1. Flow diagram of participants during the study.

between groups as an absolute effect size. Using the Epidemiological Data Analysis Program, Epidat version 4.2, with a 95% confidence level, 90% power, and a 1:1 allocation ratio, the required sample size was estimated at $n = 257$ per group ($n = 514$ total). Considering an expected attrition rate of 30%, as observed in similar studies (Borde et al., 2017; Corder et al., 2020; Sebire et al., 2018), the final sample size was set at $n = 336$ per group ($n = 672$ total).

Six classrooms per school were selected, distributed across the seventh, eighth, and ninth grades (two per grade). Sixth-grade students were excluded due to their transition from primary to secondary education, during which social networks are still developing. Tenth and eleventh grades were also excluded due to fewer scheduled PE sessions. To ensure adequate social network data, classrooms with an informed consent return rate below 60% were excluded, as this threshold is necessary for reliable SNA (Marks et al., 2013). Students were recruited within each classroom and provided with detailed study information. Informed consent forms were distributed to parents or guardians, and students provided assent before participating. Students who did not provide consent or assent participated in intervention or control activities as part of their regular PE class, but no data were collected from them.

Procedures

Four schools participated in the study, with a total sample of 879 adolescents distributed across 24 classrooms. Informed

consent was not obtained for 92 adolescents. Two schools were randomly allocated to the intervention group (12 classrooms, $n = 402$) and two to the control group (12 classrooms, $n = 385$), resulting in a total of 24 classrooms and 787 adolescents assessed at baseline (T0). The randomization sequence was generated using the online software Sealed Envelope Ltd. 2022 (Pocock, 2013) by an independent professional. To minimize performance and detection bias, several levels of blinding were implemented. Measurement staff were trained and were fully blinded to group allocation and to the content of the intervention throughout the entire study. Due to the study design, PE teachers who implemented the intervention and student participants were not blinded to the intervention, but both were blinded of group allocation. Similarly, the researcher conducting statistical analyses remained blinded to allocation until all primary analyses were completed

Intervention description

Intervention design

Prior to the implementing of the intervention, the GMB technique was applied in the two schools assigned to the experimental group to enhance contextual understanding and identify key intervention components (Hovmand, 2014). Two GMB sessions of 210 minutes each were conducted with groups of students ($n = 14$, $M = 14.4$, SD = 0.7, 57.1% girls) and ($n = 12$, $M = 14.1$, SD = 0.9, 50% girls), respectively. During these sessions, participants created two causal loop diagrams illustrating sources and actions of SS for the targeted behaviors. These diagrams were refined and validated in a follow-up 60-minute session with the same participants, resulting in a final consolidated diagram identifying key elements to be integrated into the intervention. All sessions followed structured protocols based on previous studies (Hovmand et al., 2012).

Intervention implementation

A segmentation-based social network intervention (Valente, 2012) was implemented to promote SS mechanisms among adolescents and their parents (Beets et al., 2010; Duncan et al., 2005). The intervention was embedded within the PE classes that students regularly attended, and the activities were designed following the cooperative learning pedagogical model (Dyson & Casey, 2016) and guided by the principles of Self-Determination Theory (SDT) (Ryan & Deci, 2017). Network segmentation was conducted using sociometric data from each classroom, based on clusters detected through sociometric analysis. The software Gephi 0.10.1 was employed, applying the modularity function and community detection algorithm (Blondel et al., 2008). Multiple clustering configurations were explored by adjusting the resolution parameter until identifying the most pedagogically appropriate number and size of clusters. In cases of unequal group sizes—where one group exceeded another by more than two students-two smaller subgroups were merged based on visual network analysis and the existing interpersonal connections within the network.

The intervention was conducted between February and June 2024, spanning the first semester of the academic year. It comprised ten structured PE sessions, each delivered once per week in a two-period block (100–110 minutes per session). A didactic unit was designed for the ten classes, with each session focusing on a specific type of SS (Duncan et al., 2005) related to each targeted behavior. The activities were delivered by the PE teachers at each school, who received prior training through four virtual meetings (2.5 hours each) and three personalized in-person meetings (2 hours each). The training covered essential topics such as SDT strategies (Gillison et al., 2019), cooperative learning pedagogy (Dyson & Casey, 2016), PA and ST behaviors in adolescents (Bull et al., 2020) and types and sources of SS (Duncan et al., 2005). To guarantee fidelity in the delivery of the intervention, teachers received continuous supervision and support via phone calls, WhatsApp messages, and weekly on-site visits. The intervention was led by a PhD-level teacher with 20 years of experience, a master's-level teacher with 18 years of experience, and a specialist teacher currently completing a master's degree, also with 18 years of experience. A teacher with a doctorate in education and 20 years of experience, a teacher with a master's degree in education and 18 years of experience, and a teacher specialist in the process of completing a master's degree in education with 18 years of experience, delivered the intervention. Two teachers with specialization studies in education with over 20 years of experience and a teacher with a master's degree in education with 15 years of experience were in charge of the control group.

During sessions 1 to 10, a school-based intervention within PE classes (ClassI) was implemented, aimed at enhancing SS within friend's networks to promote PA and reduce ST across all domains. Additionally, in each session, an infographic related to the session's topic was presented and discussed, and students were assigned a weekly challenge to improve these behaviors during their leisure time. Between sessions 6 and 10, in addition to ClassI, a parental intervention (ParentsI) was introduced, aimed at engaging parents in supporting their children's PA and reducing ST. Parents were contacted and added to a WhatsApp group with the assistance of the school's PE teachers. Weekly, parents received two infographics developed by the research team and two videos recorded by students. The infographics covered PA, ST, and SS, providing evidence-based recommendations. As part of the class activities, students, working in groups, created short videos (2–3-minutes) explaining various forms of SS to their parents and suggesting supportive actions. Parents received a video and an infographic on Mondays with recommendations for weekdays, and another infographic and video on Fridays with weekend strategies, aiming to foster PA and reduce ST in their children. Table 1 summarizes the components developed in the intervention and their alignment with SDT-based motivational strategies (Ahmadi et al., 2023).

The control group completed 10 instructional sessions (effective classes) through a 10-class didactic unit following the Sport Education model, which facilitates social interactions by structuring activities in teams (Siedentop et al., 2011). The activities were delivered by PE teachers, who received training in three in-person meetings (2 hours each) and ongoing support via WhatsApp and weekly visits. The intervention was led by two specialist teachers with 25 years of experience and one teacher with a master's degree and 14 years of experience.

Table 1. Weekly summary of the components of a social network-based intervention implemented in physical education classes to promote physical activity and reduce screen time through social support.

Week (Session)	Student-focused content and activities (ClassI)	Parent-focused content and activities (ParentsI)	Example of practical application	SDT-based motivational strategies
1	Introduction to the concepts of PA, ST, and SS. Classroom-based practical activities. C-BPA	N/A	Challenge: Support a friend in increasing their PA by following PA and ST recommendations.	Relatedness supportive: Encouraging peer support and care
2	Overview of international PA and ST guidelines; emphasis on motivational social support. C-BPA	N/A	Challenge: Identify close friends and encourage them to become more physically active.	Relatedness supportive: Promoting cooperation
3	Benefits of regular PA and reducing ST. Focus on informational social support.	N/A	Challenge: Follow PA and ST guidelines and educate peers about their benefits.	Competence support: Setting goals based on the guidelines
4	Types of PA and the importance of conditional social support. C-BPA	N/A	Challenge: Find a reading on PA benefits and types. Share insights with peers.	Autonomy support: Providing informational resources
5	Interrelation of PA, sedentary behaviour, and sleep. Introduction to instrumental social support.	N/A	Challenge: Invite friends to engage in PA, especially when they are using screens.	Relatedness support: Expressing affection and care
6	PA, sedentary behaviour, nutrition, and hydration in adolescence. Emphasis on social support for healthy behaviors. C-BPA	Concepts of PA, ST, and social support. Introduction to behavioral guidelines.	Challenge: Donate or lend a tool (e.g., ball, skipping rope) to help friends engage in PA.	Competence supportive: Providing opportunities for action
7	PA and ST behaviors in childhood; gender differences in social support provision. C-BPA	Motivational social support strategies to reduce ST and promote PA in children.	Challenge: Discuss the importance of PA and limiting ST with peers.	Competence supportive: Creating a space for improving effort
8	Patterns of PA and ST during weekdays and weekends. Reinforcement of informational social support. C-BPA	Informational strategies to promote PA and reduce ST.	Challenge: Invite friends to play on weekdays and encourage weekend PA.	Relatedness supportive: Promoting cooperation
9	PA and ST behaviours across different settings (school, home, transportation). Contextual application of social support. C-BPA	Companion social support strategies tailored to different environments.	Challenge: Brainstorm ways with peers to improve PA and ST habits at home, school, and during travel.	Autonomy support: Fostering alternatives to be physically active outside the school
10	Reflection on PA and ST behaviours and the role of social support in promoting healthy routines. C-BPA	Instrumental support strategies to encourage PA and limit ST.	Challenge: Motivate and support both friends and family to adopt healthier PA and ST behaviours.	Autonomy support: Providing a variety of options for SS

Note. PA = physical activity; ST = screen time; SS = social support; C-BPA = classroom-based practical activities.

Although both pedagogical models foster social interaction, their fundamental difference lies in the cooperative learning model used in the experimental group, which explicitly emphasizes social support mechanisms, whereas the Sport Education model applied in the control group does not necessarily promote SS as a core component. Additionally, no social network segmentation was conducted in the control group.

Primary and secondary outcomes

As the primary outcome, the total volume of PA across all domains and intensities was considered, based on current evidence highlighting the health benefits of total PA volume (Tarp et al., 2024) including light-intensity PA (V. Carson et al., 2013; Vieira et al., 2024). Minutes of PA reported during PE classes were excluded, as this is a mandatory activity that is not entirely dependent on the adolescent's choice. As a secondary variable, daily minutes of ST over the seven days were considered.

Data collection

PA was measured using the Questionnaire for Physical Activity Assessment "SAYCARE PA QA," which has been validated in the Colombian population (Nascimento-Ferreira et al., 2018). The questionnaire consists of 47 items and assesses the past 7 days across domains such as school, leisure time, and transportation. It measures intensity using a subjective scale: light intensity ("I do not sweat, and my breathing is normal"), moderate intensity ("I am slightly sweaty and breathing faster"), and vigorous intensity ("I am or feel very sweaty and out of breath"). For total PA, it shows good criterion validity with rho = 0.88 ($p \leq .05$) and acceptable reliability with rho = 0.60 ($p \leq .05$).

ST was measured using the Sedentary Behaviour Questionnaire "SAYCARE SB QA" (De Moraes et al., 2020), validated in the Colombian population, which consists of 5 items. It assesses the time in hours and minutes during the week and weekend spent in ST over the past seven days. For total minutes of ST, it shows low validity with rho = 0.05 and acceptable reliability with rho = 0.50. To obtain information specifically related to prolonged ST and because the questionnaire does not inquire about cell phone use, the last question of the questionnaire, which asked about time spent "Sitting reading books, studying, or working outside of school," was removed. In its place, a question was added to inquire about time spent "Watching a cell phone for hobby during leisure time."

For SS for PA, the Sallis questionnaire (2002) was used. This tool assesses five types of SS (instrumental, motivational, conditional, informational, and emotional) from different sources, including parental and friends support, using a 5-point Likert scale ranging from "Never = 1" to "Always = 5" (J. F. Sallis et al., 2002). Previous studies have reported good internal consistency with Cronbach's alpha (α) and reliability with the intraclass correlation coefficient (ICC) for friends support for PA: α = 0.90, ICC = 0.89, and for parental support for PA: α = 0.81, ICC = 0.91 (de Farias Júnior et al., 2011). Other studies have reported α = 0.72 for family support and α = 0.77 for

friend support, with moderate reliability of $r = 0.56$ and $r = 0.54$, respectively (Pirasteh et al., 2008). Another study has reported good consistency and reliability for family support ($\alpha = 0.78$, ICC = 0.81) and for friend support ($\alpha = 0.74$, ICC = 0.70) (J. F. Sallis et al., 2002). For social support related to ST, a questionnaire was validated to measure four types of support (motivational, conditional, informational, and emotional) from parents and friends using a 5-point Likert scale ranging from "Never = 1" to "Always = 5." Although the study reporting the validity and reliability of this instrument has not yet been published, the results support its validity and reliability (rho > 0.8 and ICC > 0.5).

For the friend's social network, participants were given a list of their classmates and asked to nominate their best friends without any restrictions (Collonnaz et al., 2022). To measure the SS network, they were asked to nominate classmates who provided them with SS for PA and ST. Using this information, the parameters of the social network were calculated: density (the proportion of the total number of nominations relative to the number of possible nominations), centrality (the participant's intermediation within their own network, measured as the proportion of times the participant lies on the shortest path between two nominees), homophily (nominations made to peers with similar attributes, in this case, the same level of perceived social support), friend triads (the number of times the participant is part of a triad), and new and maintained ties measured at the end of the intervention. These parameters were obtained using the Ucinet software (Everett & Freeman, 2002).

For height, a mechanical stadiometer (Tánita HR 200) was used. Weight was measured using a Health o meter professional scale, model 844KL, with a capacity of up to 200 kg and an accuracy of 0.05 kg. Established protocols were followed (Lohman et al., 1988). For body mass index, the World Health Organization were followed (de Onis et al., 2007). A generic questionnaire was used to collect sociodemographic variables. Additionally, family structure (nuclear, single-parent, other) was assessed, the Family Affluence Scale II (FAS II) was used as a socioeconomic proxy (Currie et al., 1997), and the family functionality questionnaire (APGAR) was applied (Smilkstein, 1978).

The reliability of all questionnaires was analyzed in a pilot test involving 105 adolescents from a public school, of whom 89 (mean age 14.43, SD = 1.53, 42.7% female) completed the test-retest with an 8-day interval. Reliability was measured using the intraclass correlation coefficient (ICC) through a random-effects model and absolute agreement using average measures in IBM SPSS version 25. The ICC values indicated moderate reliability for daily minutes of total PA, ICC = 0.68 (95% CI = 0.52 to 0.79) and total ST, ICC = 0.72 (95% CI = 0.57 to 0.81). SS for PA from parents had an ICC = 0.78 (95% CI = 0.66 to 0.85), SS for PA from friends ICC = 0.68 (95% CI = 0.21 to 0.79), SS for ST from parents ICC = 0.52 (95% CI = 0.28 to 0.69), and SS for ST from friends ICC = 0.83 (95% CI = 0.74 to 0.88), $p < .001$. This indicates that the questionnaire measures are consistent and reliable for use in this context.

Measures and follow-up

At baseline (T0), all variables were measured in $n = 787$ adolescents (intervention group $n = 402$, control group $n = 385$). At the fifth contact (developed class), the first follow-up (T1) was conducted, measuring PA, ST, and SS in $n = 733$ adolescents (intervention group $n = 372$, control group $n = 361$), with a follow-up loss of 6.8%. At posttest (T2), all variables were measured in $n = 713$ adolescents (intervention group $n = 370$, control group $n = 343$), with a follow-up loss of 9.4%. After the intervention, a follow-up (T3) was conducted at 10 weeks, measuring PA, ST, and SS in $n = 696$ adolescents (intervention group $n = 353$, control group $n = 343$) The total follow-up loss was relatively low (11.5%), furthermore it was gradual and the number of students withdrawn from the intervention group was similar to the control group (49 vs 42 participants), and it was due to voluntary withdrawals. Comparisons were made between those who completed and those who did not complete the intervention, and no significant differences were found between the several variables, suggesting a low risk of differential bias due to loss. On the other hand, the mixed-effects analysis allowed the inclusion of the available data in all measurements, mitigating the impact of incomplete follow-up.

Statistical analysis

Descriptive statistics were performed at baseline (T0). Due to the non-normal distribution of the data according to the Shapiro-Wilk test ($p < .001$), medians and interquartile ranges are reported for continuous variables. For categorical variables, frequencies (n) and percentages are reported. A comparison of medians between the intervention and control groups was conducted to determine differences at T0 ($p < .05$), and the Chi-square test was used for categorical variables ($p < .05$). SS network variables for PA and ST were analyzed using Ucinet 6, version 6.8 (Everett & Freeman, 2002). Means and confidence intervals are reported for these variables. For effectiveness analyses of primary and secondary outcome variables, mixed models were performed using the Restricted Maximum Likelihood (REML) method in the GAMLj module of Jamovi, version 2.5, which is open access (Gallucci, 2019). Outliers for daily minutes of PA and ST across all measurements were addressed through the winsorization process, applied only to values exceeding the upper limit calculated as ($Q3 + 1.5 \times IQR$). Extreme values were replaced with the maximum allowed value to minimize distortion in the analyses (Wilcox, 2022). No data imputation was performed, considering the type of analysis and the low follow-up loss. All analyses were conducted on an intention-to-treat basis. For SS network variables, only pre- and posttest values were included in the model, in an effort to reduce bias due to regression to the mean and initial differences.

Results

Table 2 describes the baseline characteristics of the participants. In total, 787 adolescents (52.0% girls), were evaluated in

Table 2. Baseline characteristics by group.

Variable	All ($n = 787$)	Intervention ($n = 402$)	Control ($n = 385$)	p-value
Sex, n (%)				
Girls	409 (52.0)	200 (25.4)	209 (26.6)	.2
Boys	378 (48.0)	202 (25.6)	176 (22.4)	
Age, years - Median (IQR)	13.9 (1.58)	13.9 (1.68)	14.0 (1.52)	.1
Body mass index, n (%)				
Normal weight	646 (82.1)	325 (41.3)	321 (40.8)	.3
Overweight	141 (17.9)	77 (9.8)	64 (8.1)	
FAS, n (%)				
High	26 (3.3)	16 (2.0)	10 (1.3)	.3
Middle	292 (37.1)	154 (19.6)	138 (17.5)	
Low	469 (59.6)	232 (29.5)	237 (30.1)	
APGAR, n (%)				
Functional	174 (22.1)	91 (11.6)	83 (10.5)	.5
Dysfuntional low	314 (39.9)	167 (21.2)	147 (18.7)	
Dysfuntional moderate	191 (24.3)	89 (11.3)	102 (13.0)	
Dysfuntional severe	108 (13.7)	55 (7.0)	53 (6.7)	
Family type, n (%)				
Functional	395 (50.2)	194 (24.7)	201 (25.5)	.5
Single parents	343 (43.6)	181 (23.0)	162 (20.6)	
Other	49 (6.2)	27 (3.4)	22 (2.8)	
Daily minutes of PA (Median-IQR)	35.0 (71.4)	31.5 (66.1)	39.0 (75.1)	.09
Daily minutes of ST (Median-IQR)	316 (358)	316 (342)	315 (374)	.6
Social support (Median-IQR)				
SS parents for PA	2.20 (1.60)	2.20 (1.60)	2.40 (1.60)	.3
SS friends for PA	1.40 (1.20)	1.40 (1.20)	1.40 (1.40)	.4
SS parents for ST	3.00 (1.75)	3.00 (1.75)	3.25 (2.00)	.6
SS friends for ST	1.00 (1.00)	1.00 (0.75)	1.00 (1.00)	.1
SS Network for PA (Mean-CI 95%)				
Density	0.49 (0.15/0.82)	0.74 (0.11/1.37)	0.22 (0.04/0.41)	.1
Centrality	0.26 (0.20/0.32)	0.32 (0.23/0.42)	0.19 (0.11/0.27)	.03
Homophily	0.35 (0.32/0.38)	0.43 (0.38/0.48)	0.26 (0.22/0.31)	<.001
Triads	0.02 (0.01/0.04)	0.03 (0.01/0.05)	0.02 (0.00/0.04)	.4
*New ties**	0.43 (0.37/0.49)	0.41 (0.33/0.50)	0.45 (0.37/0.54)	.5
*Keep ties**	0.15 (0.12/0.18)	0.14 (0.10/0.18)	0.16 (0.12/0.21)	.4
SS Network for ST (Mean-CI 95%)				
Density	0.92 (0.45/0.38)	0.56 (0.06/1.06)	1.29 (0.49/2.09)	.1
Centrality	0.12 (0.07/0.17)	0.12 (0.04/0.19)	0.13 (0.05/0.20)	.9
Homophily	0.24 (0.21/0.27)	0.27 (0.23/0.31)	0.21 (0.17/0.25)	.04
Triads	0.04 (0.02/0.06)	0.02 (0.00/0.03)	0.07 (0.03/0.38)	.02
*New ties**	0.22 (0.19/0.26)	0.24 (0.19/0.30)	0.20 (0.15/0.26)	.2
*Keep ties**	0.08 (.05/0.10)	0.06 (0.03/0.09)	0.10 (0.06/0.14)	.1

Note. IQR = interquartile range; FAS = family affluence scale; APGAR = family functioning questionnaire; PA = physical activity; ST = screen time; SS = social support. *Compared between pre-intervention and post-intervention.

the study. The median age was 13.9 (IQR = 1.58), and 82.1% had a normal weight according to BMI-for-age. The socio-economic status questionnaire (FAS) indicates that 59.6% of the adolescents reported low-income families, and 37.1% reported middle-income families. Additionally, 50.2% had functional families (APGAR), and 43.6% had single-parent families, with no differences between groups ($p > .05$). The median baseline PA was 35 minutes per day, and ST was 316 minutes per day. No significant differences were observed between the control group and the intervention group ($p > .05$). SS variables indicate baseline differences in homophily for social support related to PA and ST, centrality for SS related to PA, and triads for SS related to ST ($p < .05$).

Primary outcomes

A mixed model was developed using the REML method to determine the effectiveness of the intervention and the predictive variables on PA behaviors in a parsimonious manner. To determine the random intercept variables for PA, the literature related to social network interventions with mixed model analyses was first considered, which includes the subject and the classroom as a social network (Amirkhanian et al., 2015; van Woudenberg et al., 2020). Additionally, the school was considered. The variability of PA attributable to these variables was evaluated using an independent random intercept model, calculating the Intraclass Correlation Coefficient (ICC). The highest variability was attributed to subject (ICC = 0.445), followed by the classroom (ICC = 0.04) and the school (ICC = 0.01). The Likelihood Ratio Test (LRT) was significant for all variables in the model ($p < .001$). The analysis began with a simple model including only the subject as a random intercept, followed by the inclusion of the classroom variable. According to the Chi-square test, the model improved significantly ($X2(1) = 15.84$, $p < .001$). When the school intercept was included, the model showed no improvement, so this variable was discarded. Subsequent models included subject and the classroom as random effects, treating the classroom as a social network.

For the fixed-effects variables, the group, sex, measurements, and the interaction between measurements and time were included to identify the effects between groups across different measurements. The model was adjusted with covariates such as

baseline PA, parental SS, and friends SS, which are established as correlates and determinants of PA in adolescents (J. F. Sallis et al., 2000; Sterdt et al., 2014). Additionally, the following friends SS network measures were included as covariates: density, centrality, homophily, and triads. Finally, variables related to new ties and keep ties over time were included, comparing SS networks before and after the intervention. These variables were added to the model sequentially, ensuring that each addition provided a significant improvement based on Chi-square critical values. The omnibus test indicated significant differences in the following variables: group 33($F(1, 19.9) = 5.11$, $p = .03$), sex ($F(1, 763.3) = 47.78$, $p < .001$), measurements ($F(3, 2078.3) = 35.25$, $p < .001$), baseline PA ($F(1, 804.5) = 749.24$, $p < .001$), parental SS ($F(1, 2139.7) = 13.30$, $p < .001$), friends SS ($F(1, 2503.5) = 20.01$, $p < .001$), group*measurements interaction ($F(3, 2073.7) = 4.50$, $p = .004$), and homophily ($F(1, 2604.6) = 4.10$, $p = .04$). Once the model was adjusted for fixed effects and covariates, the variability explained by the subject decreased (ICC = 0.15, LRT = 72.9, $p < .001$), as did the variability for the classroom (ICC = 0.02, LRT = 9.3, $p = .002$).

The group*time interaction indicates that the intervention had a positive effect on total PA, with an increase of 12.2 minutes per day between baseline (T0) and posttest (T2) (95% CI: 1.9 to 22.5, $p = .02$). The greatest difference was achieved from baseline (T0) to week five (T1), during which the ClassI component was implemented (b = 17.4, 95% CI = 7.2 to 27.5, $p < .001$). No changes were observed between T1 and T2, during which the ClassI + ParentsI component was implemented. The main effects, considering all four measurements, indicate a positive impact on sustainability over time (b = 8.2, 95% CI = 1.1 to 15.7, $p = .03$). Boys exhibited 17.1 more minutes of PA compared to girls (95% CI = 12.2 to 21.9, $p < .001$). Baseline PA, as well as parental and friends SS, predicted PA within the model, with increases of 0.6, 3.7, and 4.6 minutes, respectively, for each unit increase in these variables ($p < .001$). Among the friends SS network variables, only homophily was significantly associated, predicting an increase of 6.8 minutes of PA (95% CI = 0.2 to 13.7, $p = .04$). The full model explains 48% of the variability in PA among adolescents (marginal $R^2 = 0.376$, conditional $R^2 = 0.480$, as measurements of effect size). Table 3 shows the mixed effects model for PA.

Secondary outcomes

For the mixed model of ST, the same procedure was followed for the random intercept. The subject variable explained the highest variability of ST (ICC = 0.39), followed by the classroom variable (ICC = 0.05), with the LRT test showing $p < .001$. The simple model included the subject as the first random intercept variable, and then the classroom variable was added, improving the model ($X2(1) = 31.36$, $p < .001$). Subsequent models included both the subject and the classroom as random intercepts. The same fixed effects and covariates from the PA model were used. The omnibus test for fixed effects indicated significant differences in the model for the following variables: measurements ($F(3, 2222.2) = 6.35$, $p < .001$) and baseline ST ($F(1, 717.6) = 682.4$, $p < .001$). The group*measurements interaction showed a marginal difference ($F(3, 2073.2) = 2.61$, $p = .05$). No significant differences were found in the other variables. The variability explained by the subject decreased once fixed effects and covariates were included in the model (ICC = 0.172, LRT = 93.12, $p < .001$), as did the variability for the classroom (ICC = 0.0080, LRT = 2.63, $p = .1$). Although the classroom variable explained very

Table 3. Fixed and random effects model for physical activity.

Random effects				s^2 (SD)	ICC	LRT	p-value
	Subject			417.2 (20.4)	0.151	72.9	*<.001**
	Classroom			47.9 (6.9)	0.020	9.3	*0.002**
	Residual			2337.9 (48.3)			
Fixed effects		***b***	***SE***	***DF***	***CI 95%***		***p-value***
Intercept		65.8	1.8	19.7	62.2	69.5	*<.001**
Group	*Intervention -Control*	8.2	3.7	19.9	0.9	15.4	*0.03**
Sex	*Boys-Girls*	17.4	2.4	766.9	12.5	22.2	*<.001**
Measures	*T1-T0*	14.1	2.8	2201.1	8.5	19.1	*<.001**
	T2-T1	−2.8	3.0	2199.0	−8.7	3.0	*0.3*
	T2-T0	11.3	3.1	2243.9	5.1	17.4	*<.001**
	T3-T2	17.5	3.0	2214.7	11.5	23.5	*<.001**
Physical activity	*Baseline*	0.6	0.02	806.7	0.58	0.68	*<.001**
Social support	*Parents*	3.7	1.01	2133.0	1.7	5.7	*<.001**
	Friends	4.6	1.06	2525.1	2.5	6.7	*<.001**
Group*Measures	*Intervention-control*T1-T0*	17.4	5.1	2063.6	7.2	27.5	*<.001**
	*Intervention-control*T2-T1*	−5.1	5.3	2068.4	−15.6	5.3	*0.2*
	*Intervention-control*T2-T0*	12.2	5.2	2083.3	1.9	22.5	*0.02**
	*Intervention-control*T3-T2*	4.7	5.4	2089.3	−5.8	15.3	*0.3*
SS network perceived for PA	*Density*	−.04	0.2	2174.6	−0.5	0.4	*0.8*
	Centrality	−2.1	1.9	2629.0	−5.9	1.7	*0.2*
	Homophily	6.9	3.4	2604.6	0.2	13.7	*0.04**
	Triads	6.8	6.1	2627.1	−5.1	18.8	*0.2*
	New ties	−.18	2.6	2587.8	−5.3	4.9	*0.9*
	Keep ties	4.7	4.6	2535.8	−4.2	13.8	*0.3*

Note. s^2 = variance; SD = standard deviation; ICC = intraclass correlation index; LRT = likelihood ratio test; b = estimated daily minutes of physical activity; SE = standard error; DF = degrees of freedom; CI = confidence interval; T0 = baseline; T1 = follow-up week five; T2 = post-intervention; T3 = follow-up week ten post-intervention.
*Statistically significant differences $p < .05$.

little variability and was not statistically significant in the model, it was retained due to theoretical plausibility, given that the intervention was based on a social network approach, where each classroom was treated as a network of friends.

The group*measurements interaction indicates that the intervention was effective in reducing ST by 56.7 minutes per day between T0 and T2 (95% CI: −105.2 to −8.1, $p = .02$). Despite this reduction, the main effects suggest that the effectiveness was not sustained over time (b = −18.8, 95% CI: −47.5 to 9.8, $p = .2$). The greatest reduction in ST was achieved between week 5 and week 10, when the ParentsI component was included alongside the ClassI component. However, the effectiveness was lost between post-intervention and the 10-week follow-up. Parental and friends SS were not significant predictors, nor were the SS network variables for ST. Baseline ST significantly predicted ST in the model, with an increase of 0.5 minutes per day (95% CI: 0.52 to 0.61, $p < .001$). The full model explains 41.5% of the variability in SB (marginal $R^2 = 0.288$, conditional $R^2 = 0.415$, as measurements of effect size). Table 4 shows the mixed effects model for ST.

In both models, the assumption of normality for the residuals was not met (Shapiro-Wilk test, $p < .001$). However, a visual inspection of the histogram and the Q-Q plot showed that the residual data did not deviate significantly from the reference line. Additionally, post-hoc analyses (data not shown) confirmed the significance of each variable for both the PA model and the ST model (Bonferroni test, $p < .05$). Graphs 1 and 2 show the evolution of the means for PA and ST variables, measured in daily minutes, at baseline (T0), the 5-week follow-up (T1), post-intervention (T2), and the 10-week follow-up after the intervention (T3).

Discussion

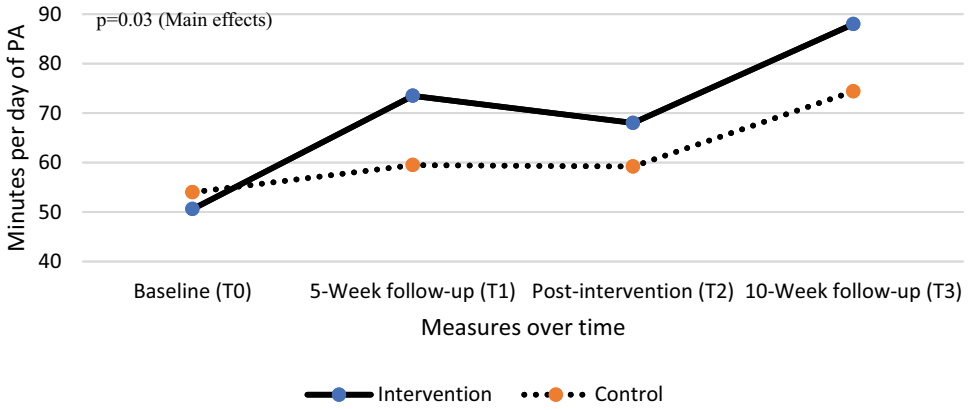
This study aimed to determine the effectiveness of a social network intervention using a segmentation approach, specifically promoting the mechanism of SS from friends and parents, on PA and ST among school adolescents. An intervention component was developed for PE classes, called ClassI, implemented between weeks 1–10, and a ParentsI component, combined with ClassI, implemented between weeks 6–10. A mixed-model analysis indicates that the PA intervention was effective, increasing PA by 12.2 minutes among adolescents between baseline and post-intervention. This effectiveness stabilized after the intervention, and the main effects suggest sustainability up to 10 weeks post-intervention. Previous studies have shown that social network-based interventions can be effective in improving health-related behaviors within adolescent social networks, such as reducing sugary drink consumption and smoking (Campbell et al., 2008; Smit et al., 2021).

The results of this study are consistent with other social network-based interventions that have also been effective in improving PA-related behaviors within social networks. For example, a study conducted with Italian pre-adolescents increased PA by 24.4 minutes per week through a network alteration and induction intervention that promoted social influence and social pressure (Proestakis et al., 2018). In England, a study with adolescent girls, based on an individual network intervention promoting social influence, achieved an increase of 6 minutes of daily PA (Sebire et al., 2018). Meanwhile, a study in the United States, also based on an individual network intervention promoting influence, norms, and social support, increased moderate PA by 14 minutes per day (Barr-Anderson et al., 2012). The difference with these

Table 4. Fixed and random effects model for screen time.

Random effects			s^2 (SD)		ICC	LRT	p-value
	Subject		10868 (104.2)		0.172	93.1	<.001*
	Classroom		467 (21.6)		0.008	2.5	0.1
	Residual		52021 (228.1)				
Fixed effects		***b***	***SE***	***DF***	***CI 95%***		***p-value***
Intercept		391.4	7.3	20.9	377.1	405.7	<.001*
Group	*Intervention -Control*	−18.8	14.6	20.9	−47.5	9.8	0.2
Sex	*Boys-Girls*	−17.4	11.7	775.7	−40.4	5.5	0.1
Measures	*T1-T0*	3.5	13.1	2158.2	−22.1	29.3	0.7
	T2-T1	−35.8	13.4	2140.4	−62.1	−9.5	0.008*
	T2-T0	−32.2	13.9	2193.6	−59.5	−4.9	0.02*
	T3-T2	63.7	14.7	2311.8	34.9	92.6	<.001*
Screen time	*Baseline*	0.5	0.02	717.6	0.52	0.61	<.001*
Social support	*Parents*	2.5	4.4	2655.1	−6.2	11.3	0.5
	Friends	9.0	5.0	2531.4	−0.8	18.8	0.07
Group*Measures	*Intervention-control*T1-T0*	8.3	2.4	2063.3	−39.4	56.1	0.7
	*Intervention-control*T2-T1*	−48.3	25.2	2072.0	−97.7	1.0	0.05
	*Intervention-control*T2-T0*	−56.7	24.7	2069.8	−105.2	−8.1	0.02*
	*Intervention-control*T3-T2*	7.80	25.5	2084.8	−42.3	57.9	0.7
SS network for ST	*Density*	−0.2	1.7	2572.9	−3.6	3.1	0.8
	Centrality	−15.1	13.7	2598.0	−42.0	11.7	0.2
	Homophily	−4.0	18.8	2602.7	−41.0	32.8	0.8
	Triads	23.7	45.3	2566.1	−65.1	112.5	0.6
	New ties	20.6	17.1	2565.2	−12.9	54.2	0.2
	Keep ties	−32.8	26.4	2526.9	−84.7	19.0	0.2

Note. s^2 = variance; SD = standard deviation; ICC = intraclass correlation index; LRT = likelihood ratio test; b = estimated daily minutes of physical activity; SE = standard error; DF = degrees of freedom; CI = confidence interval; T0 = baseline; T1 = follow-up week five; T2 = post-intervention; T3 = follow-up week ten post-intervention.
*Statistically significant differences $p < .05$.



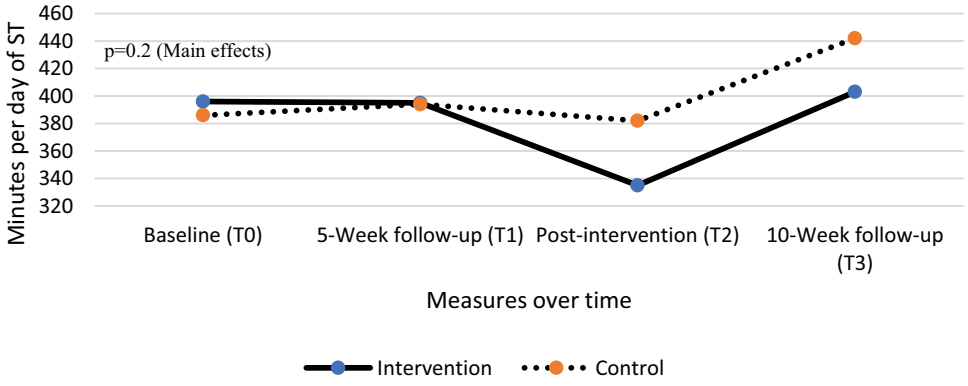
Graphic 1. Marginal means of minutes of physical activity.

previous studies lies in the fact that the current intervention aligned a group-based approach through social network segmentation and specifically promoted the mechanism of SS from friends and parents within PE classes. Other interventions have promoted mechanisms such as social norms, social pressure, and social influence (Proestakis et al., 2018; Sebire et al., 2018) and only one of them promoted social support alongside norms and social influence (Barr-Anderson et al., 2012).

On the other hand, there is evidence of social network-based interventions using an individual approach that have not been effective in promoting PA among adolescents (Jago et al., 2021; van Woudenberg et al., 2018, 2020). These unsuccessful interventions utilized an individual network approach, focusing on training central members of the network to promote behavior change among the rest of the group. These members were selected based on peer nominations, and only individuals with a certain level of popularity within the network were trained to drive behavioral change. The present study differs from these interventions because the educational component, ClassI, focused on SS was directed at all members of the network. The goal was to help them understand the elements of different types of SS and develop these within their network whenever possible, aiming to encourage PA and reduce ST. The segmentation of groups was implemented to enhance the SS mechanism and integrate it into PE class activities through the principles of the cooperative learning pedagogical model.

The methodological differences in intervention between this study and previous interventions are important. These previous studies have intervened from individual approaches, which are based on the dissemination of information through influential actors. Group intervention approaches, on the other hand, can strengthen norms and behaviors within a network and have been shown to have great potential in school settings (Prochnow et al., 2020; Sawka et al., 2014). Likewise, unlike interventions focused on norms and social influence (Proestakis et al., 2018; Sebire et al., 2018), the present study specifically promoted emotional, instrumental, and companionship support from friends and parents. This approach may have the potential to explain increases in PA behaviors observed up to 10 weeks post-intervention.

The model indicates that the ClassI component, focusing on friends SS within PE classes, was crucial for achieving the intervention's effectiveness in increasing PA. When the ParentsI component was added, no significant changes were observed, suggesting that friends SS is more influential in promoting PA. However, evidence shows that both parental and friends SS are positively associated with adolescent PA in cross-sectional and longitudinal studies (Gill et al., 2017; Mendonça et al., 2014). The results also show that girls engage in less PA than boys, which aligns with current evidence (Guthold et al., 2020). In this regard, a systematic review on SS and PA in adolescent girls concluded that different types and sources of SS are associated with increased PA. Although SS is not a strong predictor of PA, it is possible that



Graphic 2. Marginal means of minutes of screen time.

support from parents and friends could be key to overcoming this gender disparity related to PA (Laird et al., 2016). Evidence from intervention studies specifically developing SS to promote PA in adolescent girls is scarce. Two secondary analyses of interventions have concluded that SS, in general, is a mediator of PA in adolescent girls (L. B. Robbins et al., 2019) and that support from mothers is particularly important for promoting PA (L. B. Robbins et al., 2018). Therefore, SS may represent an opportunity to encourage girls to engage in more PA.

The gender differences observed in the PA behavior of this study suggest that future social network interventions integrate methods with gender perspectives. Evidence indicates that support from peers, family, and teachers is one of the facilitators of PA in adolescent girls, and that to overcome the gender gap it is essential to incorporate approaches with gender perspectives (Duffey et al., 2021). For this reason, social network interventions aimed at improving PA in girls can benefit from pedagogical and contextual strategies such as social connection, enjoyment, and access to PA programs and safe environments (Martins et al., 2021).

As a secondary outcome, the effectiveness of the intervention on daily minutes of ST was explored. The model indicates that the intervention was effective between baseline (T0) and post-intervention (T2), achieving a reduction of 56.7 minutes of daily ST in the intervention group. This reduction was achieved after including the ParentsI component in week 6. This reinforces evidence showing that family support is a key factor in adolescent SB behaviors (Norman et al., 2005).

Despite achieving significant effects during the intervention period, the follow-up measure at 10 weeks post-intervention (T3) demonstrated that the changes were not sustainable for ST. These results are consistent with the literature. Literature syntheses show that for this behavior, short intervention periods tend to have transient effects, especially when not reinforced with other behavioral strategies such as progressive goals, continuous feedback, planning, behavior repetition and substitution, among others (Jones et al., 2021; Lewis et al., 2021). Furthermore, ST is influenced by other contextual and family factors such as household norms, and by social determinants such as safe environments and access to recreational spaces, which makes it necessary to implement multilevel strategies (Tock et al., 2025). The intervention in the present study focused solely on social support as a behavioral strategy and did not address other determinants essential for sustainability. Future research should consider more behavioral strategies and integrate them into the context to achieve greater sustainability of the effects.

Since the model shows that parental and friends SS does not significantly reduce ST. But, there was a significant reduction of ST was identified when the parental component was implemented (T1 and T2), it is likely that the intervention's effectiveness is not due to this mechanism. Possibly other mechanisms, such as social norms or social pressure, may have emerged from the complexity of social interactions when the ParentsI component was introduced. Once the intervention ended, the norms or pressure from parents may have diminished, causing the effectiveness to fade out. However, since these mechanisms were not measured, we cannot attribute the change to any of them. The results of this study differ from an intervention aimed at reducing ST in Brazilian adolescents, which concluded that school-based SS (from friends and teachers) mediated the effectiveness in reducing ST, while family support did not play a mediating role (Bandeira et al., 2020).

Previous social network-based interventions have addressed SB, measured objectively in daily minutes. Only one study found effectiveness, reducing SB by 23 minutes between posttest and the 4-month follow-up (Sebire et al., 2018). Two other interventions did not achieve effectiveness in reducing SB (Bell et al., 2017; Jago et al., 2021). Typically, these interventions addressed SB alongside another variable, such as PA. For example, a social network intervention by Bell et al. (2017) promoted SS to encourage PA and improve dietary habits to reduce obesity in adolescents. However, it was not effective, concluding that promoting two behavioral changes within the network may be too complex and recommending a focus on a single behavior change (Bell et al., 2017). The present study focused on two behaviors, both considered highly complex (Pettee Gabriel et al., 2012) achieving positive results, particularly for PA. For ST, a parental intervention with more time and incorporating other social interactions beyond SS might yield more sustainable results. Similarly, other social aspects should be considered in friends SS interventions for ST.

The observed increase of 12.2 minutes/day in PA and the reduction of 56.7 minutes in ST represent significant effects, considering the context of findings from previous studies, which have documented increases ranging from 6 (Sebire et al., 2018) to 14 minutes (Barr-Anderson et al., 2012) per day of PA, and reductions in ST of around 23 minutes per day (Sebire et al., 2018). This magnitude of effect in minutes of physical activity represents approximately 20% of the daily recommendation for adolescents, while the 56.7-minute/day reduction in screen time corresponds to almost half of the maximum recommended daily exposure. From a public health perspective, it is likely that these changes, if sustained over time, will have a positive effect on adolescent health.

This study explored the extent to which SS network variables explained the outcomes, PA and ST, pioneering this type of analysis as no prior evidence exists. Only homophily (the tendency to connect with peers who have similar attributes) was positively associated with adolescent PA. However, since significant differences between groups were found at baseline, this association may not be entirely attributable to the intervention. Previous observational studies have analyzed friendship network parameters. For example, Sawka et al. (2014) found that denser social networks in children were associated with more SB compared to less dense networks, while having active friends was positively related to being more active. Other studies also found that having more active friends in the network was positively associated with individual activity levels, and an inverse relationship was observed between having active friends and engaging in SB (Arango-Paternina et al., 2022; Marks et al., 2016). A systematic review documented that among friend network variables, centrality, network composition, and homophily were the social network parameters associated with PA in children and adolescents (Prochnow et al.,

2020). These studies are cross-sectional, and the parameters analyzed pertain to friendship networks, not social support networks. It is worth noting that friendship networks tend to be larger compared to social support networks.

Strengths and limitations

Among the strengths of the study is its participatory design, which allowed the use of systems dynamics tools such as GMB to engage stakeholders and identify key aspects of the intervention, such as the ParentsI component and specific friends SS actions to promote PA. Additionally, the complementary use of social network analysis enabled the identification of friend network parameters and the enhancement of the SS mechanism within PE classes. Furthermore, the study is well-grounded theoretically, as it aligns SDT with social network theory, SS theory, and cooperative learning principles to guide the intervention activities.

One limitation of the study, also reported in previous research, relates to the requirement of informed consent as a legal prerequisite for collecting student data (van Woudenberg et al., 2018). Students whose consent forms were not signed could not be included, which may have affected the social network measures used for group segmentation. However, all students were included in groups based on social connections identified by their peers. Another limitation was that the implemented strategies were incorporated in the two components, ClassI and ParentsI, with this design it was not possible to identify the isolated effects of individual strategies. The use of self-report questionnaires, which may introduce bias in behavior measurements was a limitation. To minimize this, reliability pilot tests were conducted, and a pilot intervention was carried out using the same questionnaires and measurement personnel, who were well-trained and followed established protocols for questionnaire administration. Although the pilot test detected moderate reliability for the scales used to measure physical activity and screen time, the risk of bias was present. For future studies, an alternative could be to use procedures that guarantee greater reliability, such as accelerometers.

Given that the questionnaires were administered four times, the measurement team had to maintain the motivation and focus of the adolescents to ensure responses were as objective and accurate as possible. However, social desirability bias may have influenced the responses. First, since the educational component emphasized the importance of PA and the negative aspects of ST, adolescents might have adjusted their reported behaviors, particularly in the T2 and T3 measurements. Second, as adolescents became more aware of the behaviors being addressed, they may have responded more thoughtfully in the later measurements.

Another limitation was that the intervention was conducted only in public schools in an urban area. The characteristics of urban and public schools, as opposed to rural and private schools, can be differentiated in terms of levels of socioeconomic vulnerability, availability of resources for structured PA, patterns of exposure to screen use, as well as the structure of family and friend support networks for such behaviors. Future interventions could include comparisons between private schools and rural areas to yield more generalizable results. Additionally, the dynamics of the schools themselves posed challenges. The ClassI component, delivered during PE classes, was sometimes interrupted due to school closures for reasons such as external exams, union activities, civic or cultural events, etc. These occasional interruptions were similar for the participant schools and did not affect the content or number of PE sessions. But it affected the planned continuity to some extent. To address this, the number of completed classes was tracked to ensure that all institutions reached the 10 planned contacts, ensuring a homogeneous intervention dose for both the control and intervention groups.

Implications

The findings highlight the benefits of social network interventions in promoting PA and reducing ST. They also underscore the potential of integrating theoretical frameworks that foster socialization skills, such as social support and the principles of the cooperative learning pedagogical model, into PE classes. Additionally, the study demonstrates that PE classes play a significant role in promoting healthy behaviors among adolescents through the application of participatory research during the curriculum design. However, implementing practice-based models can pose a significant challenge in shifting teachers' instructional approaches. Similarly, the use of systems thinking tools like GMB and the creation of Causal Loop Diagrams (CLDs) can be challenging for both teachers and students. Therefore, training in these elements is essential to transform PE classes into spaces for socialization and the promotion of healthy behaviors. Finally, the use of participatory tools like Group Model Building (GMB) and their complementation with Social Network Analysis (SNA) can be highly beneficial in school-based interventions, helping to understand and address complex problems in a more contextualized and effective manner. This requires the involvement and commitment of families to establish connections that provide strategies for maintaining adequate PA levels and combating excessive SB among adolescents. It is also crucial to establish clear school policies and guidelines on screen use in both school and family contexts, combined with alternative educational strategies.

Suggestions for future research

For future research, it is recommended to delve deeper into the different types of SS (instrumental, motivational, companionship, informational) provided by friends and parents, and their impact on adolescents' PA and ST behaviors. Longitudinal studies are also suggested to evaluate changes in these behaviors in relation to SS dynamics over longer periods. Future interventions should continue to focus on and evaluate specific strategies related to reducing ST, based on co-design and involving both schools and families to assess potential sustainable solutions for this behavior.

Further exploration of the characteristics of social networks and how they can be leveraged to promote healthy behaviors is

also recommended. Replicating this type of network intervention in other contexts would help assess the generalizability of the results. Finally, future research should address sociocultural aspects of the context, including norms that influence the acceptance and success of implementing PA and ST interventions. Comparing participatory models with other approaches could help identify contextual elements relevant to the success and sustainability of interventions.

Conclusions

The social support network intervention in PE classes was effective in increasing daily minutes of PA and reducing ST among adolescents. However, interventions need to be enriched to ensure the sustainability of these effects over time, particularly for ST. The involvement of stakeholders and the co-creation of the intervention through GMB were key elements in the intervention design. GMB and SNA were useful in understanding the problem and identifying leverage points within the system for subsequent intervention. The integration of strategies to promote SS in PE classes was facilitated by the cooperative learning teaching model. Additionally, involving parents in the initiative highlighted the importance of integrating system actors to address complex behaviors. Among the SS network parameters, only homophily partially explained changes in daily minutes of PA. The other parameters were not relevant in explaining changes in PA or ST. Therefore, further studies are needed to explore other social mechanisms that better explain changes in PA and ST.

Acknowledgments

Authors are grateful to the students, physical education teachers, and directors of schools involved in the study.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) reported there is no funding associated with the work featured in this article.

ORCID

José Petro-Petro http://orcid.org/0000-0003-0853-6929
Carlos Mario Arango-Paternina http://orcid.org/0000-0002-5263-3139
Fredy Alonso Patiño-Villada http://orcid.org/0000-0003-4419-0750

Data availability statement

All data from the corresponding author is available on reasonable request.

References

Abreu, T. C., Beulens, J. W. J., Heuvelman, F., Schoonmade, L. J., & Mackenbach, J. D. (2024). Associations between dimensions of the social environment and cardiometabolic health outcomes: A systematic review and meta-analysis. *BMJ Open*, *14*(8), e079987. https://doi.org/10.1136/bmjopen-2023-079987

Ahmadi, A., Noetel, M., Parker, P., Ryan, R. M., Ntoumanis, N., Reeve, J., Beauchamp, M., Dicke, T., Yeung, A., Ahmadi, M., Bartholomew, K., Chiu, T. K. F., Curran, T., Erturan, G., Flunger, B., Frederick, C., Froiland, J. M., González-Cutre, D., Haerens, L., … Lonsdale, C. (2023). A classification system for teachers' motivational behaviors recommended in self-determination theory interventions. *Journal of Educational Psychology*, *115*(8), 1158–1176. https://doi.org/10.1037/edu0000783

Amirkhanian, Y. A., Kelly, J. A., Takacs, J., McAuliffe, T. L., Kuznetsova, A. V., Toth, T. P., Mocsonaki, L., DiFranceisco, W. J., & Meylakhs, A. (2015). Effects of a social network HIV/STD prevention intervention for MSM in Russia and Hungary: A randomized controlled trial. *AIDS*, *29*(5), 583–593. https://doi.org/10.1097/QAD.0000000000000558

Anderson, E., & Durstine, J. L. (2019). Physical activity, exercise, and chronic diseases: A brief review. *Sports Medicine and Health Science*, *1*(1), 3–10. https://doi.org/10.1016/j.smhs.2019.08.006

Arango-Paternina, C., Lema-Gómez, L., Eusse-López, C., Petro, J. L., Petro-Petro, J., López-Sánchez, M., Watts-Fernández, W., & Perea-Velásquez, F. (2022). Composition of friendship networks and health-related behaviors in adolescents. *Merrill-Palmer Quarterly*, *68*(1), 1–24. https://doi.org/10.1353/mpq.2022.0001

Arundell, L., Fletcher, E., Salmon, J., Veitch, J., & Hinkley, T. (2016). A systematic review of the prevalence of sedentary behavior during the after-school period among children aged 5-18 years. *International Journal of Behavioral Nutrition and Physical Activity*, *13*(1), 93. https://doi.org/10.1186/s12966-016-0419-1

Bandeira, A. D. S., Silva, K. S., Bastos, J. L. D., Silva, D. A. S., Lopes, A. D. S., & Barbosa Filho, V. C. (2020). Psychosocial mediators of screen time reduction after an intervention for students from schools in vulnerable areas: A cluster-randomized controlled trial. *Journal of Science and Medicine in Sport*, *23*(3), 264–269. https://doi.org/10.1016/j.jsams.2019.09.004

Barr-Anderson, D. J., Laska, M. N., Veblen-Mortenson, S., Farbakhsh, K., Dudovitz, B., & Story, M. (2012). A school-based, peer leadership physical activity intervention for 6th graders: Feasibility and results of a pilot study. *Journal of Physical Activity and Health*, *9*(4), 492–499. https://doi.org/10.1123/jpah.9.4.492

Baugh Littlejohns, L., Near, E., McKee, G., Rasali, D., Naiman, D., & Faulkner, G. (2023). A scoping review of complex systems methods used in population physical activity research: Do they align with attributes of a whole system approach? *Health Research Policy and Systems*, *21*(1), 18. https://doi.org/10.1186/s12961-023-00961-3

Beets, M. W., Cardinal, B. J., & Alderman, B. L. (2010). Parental social support and the physical activity-related behaviors of youth: A review. *Health Education & Behavior*, *37*(5), 621–644. https://doi.org/10.1177/1090198110363884

Bell, S. L., Audrey, S., Cooper, A. R., Noble, S., & Campbell, R. (2017). Lessons from a peer-led obesity prevention programme in English schools. *Health Promotion International*, *32*(2), 250–259. https://doi.org/10.1093/heapro/dau008

Berkman, L. F., Kawachi, I., & Glymour, M. M. (2014). Social network epidemiology. In L. F. Berkman & I. Kawachi (Eds.), *Social epidemiology* (pp. 234–289). Oxford University Press.

Bidzan-Bluma, I., & Lipowska, M. (2018). Physical activity and cognitive functioning of children: A systematic review. *International Journal of Environmental Research and Public Health*, *15*(4), 800. https://doi.org/10.3390/ijerph15040800

Blondel, V. D., Guillaume, J.-L., Lambiotte, R., & Lefebvre, E. (2008). Fast unfolding of communities in large networks. *Journal of Statistical Mechanics: Theory and Experiment*, *2008*(10), P10008. https://doi.org/10.1088/1742-5468/2008/10/P10008

Borde, R., Smith, J. J., Sutherland, R., Nathan, N., & Lubans, D. R. (2017). Methodological considerations and impact of school-based interventions on objectively measured physical activity in adolescents: A systematic review and meta-analysis. *Obesity Reviews*, *18*(4), 476–490. https://doi.org/10.1111/obr.12517

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J.-P., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., … Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British Journal of Sports Medicine*, *54*(24), 1451. https://doi.org/10.1136/bjsports-2020-102955

Campbell, S. F., Holliday, J., Audrey, S., Bloor, M., Parry-Langdon, N., Hughes, R., & Moore, L. (2008). An informal school-based peer-led intervention for smoking prevention in adolescence (ASSIST): A cluster randomised trial. *The Lancet*, *371*(9624), 1595–1602. https://doi.org/10.1016/S0140-6736(08)60692-3

Cardon, G., & Salmon, J. (2020). Why have youth physical activity trends flatlined in the last decade? Opinion piece on "global trends in insufficient physical activity among adolescents: A pooled analysis of 298 population-based surveys with 1.6 million participants" by Guthold, et al. *Journal of Sport and Health Science*, *9*(4), 335–338. https://doi.org/10.1016/j.jshs.2020.04.009

Carson, V., Hunter, S., Kuzik, N., Gray, C. E., Poitras, V. J., Chaput, J.-P., Saunders, T. J., Katzmarzyk, P. T., Okely, A. D., Gorber, S. C., Kho, M. E., Sampson, M., Lee, H., & Tremblay, M. S. (2016). Systematic review of sedentary behaviour and health indicators in school-aged children and youth: An update. *Applied Physiology, Nutrition, and Metabolism*, *41*(6 (Suppl. 3), S240–S265. https://doi.org/10.1139/apnm-2015-0630

Carson, V., Ridgers, N. D., Howard, B. J., Winkler, E. A. H., Healy, G. N., Owen, N., Dunstan, D. W., & Salmon, J. (2013). Light-intensity physical activity and cardiometabolic biomarkers in US adolescents. *PLOS ONE*, *8*(8), e71417. https://doi.org/10.1371/journal.pone.0071417

Collonnaz, M., Riglea, T., Kalubi, J., O'Loughlin, J., Naud, A., Kestens, Y., Agrinier, N., & Minary, L. (2022). Social network analysis to study health behaviours in adolescents: A systematic review of methods. *Social Science & Medicine*, *315*, 115519. https://doi.org/10.1016/j.socscimed.2022.115519

Corder, K., Sharp, S. J., Jong, S. T., Foubister, C., Brown, H. E., Wells, E. K., Armitage, S. M., Croxson, C. H. D., Vignoles, A., Wilkinson, P. O., Wilson, E. C. F., & van Sluijs, E. M. F. (2020). Effectiveness and cost-effectiveness of the GoActive intervention to increase physical activity among UK adolescents: A cluster randomised controlled trial. *PLOS Medicine*, *17*(7), e1003210. https://doi.org/10.1371/journal.pmed.1003210

Currie, C., Elton, R., Todd, J., & Platt, S. (1997). Indicators of socioeconomic status for adolescents: The WHO health behaviour in school-aged children survey. *Health Education Research*, *12*(3), 385–397. https://doi.org/10.1093/her/12.3.385

de Farias Júnior, J. C., da Silva Lopes, A., Siqueira Reis, R., Nascimento, J., Vieira Do Ferreti Borgatto, A., & Curi Hallal, P. (2011). Development and validation of a questionnaire measuring factors associated with physical activity in adolescents. *Revista Brasileira de Saúde Materno Infantil*, *11*(3), 301–312. https://doi.org/10.1590/S1519-38292011000300011

de Greeff, J. W., Bosker, R. J., Oosterlaan, J., Visscher, C., & Hartman, E. (2018). Effects of physical activity on executive functions, attention and academic performance in preadolescent children: A meta-analysis. *Journal of Science and Medicine in Sport*, *21*(5), 501–507. https://doi.org/10.1016/j.jsams.2017.09.595

de la Haye, K., Robins, G., Mohr, P., & Wilson, C. (2011). How physical activity shapes, and is shaped by, adolescent friendships. *Social Science & Medicine*, *73*(5), 719–728. https://doi.org/10.1016/j.socscimed.2011.06.023

De Moraes, A. C. F., Nascimento-Ferreira, M. V., Forjaz, C. L. D. M., Aristizabal, J. C., Azzaretti, L., Nascimento Junior, W. V., Miguel-Berges, M. L., Skapino, E., Delgado, C., Moreno, L. A., & Carvalho, H. B. (2020). Reliability and validity of a sedentary behavior questionnaire for South American pediatric population: SAYCARE study. *BMC Medical Research Methodology*, *20*(1), 5. https://doi.org/10.1186/s12874-019-0893-7

de Onis, M., Onyango, A. W., Borghi, E., Siyam, A., Nishida, C., & Siekmann, J. (2007). Development of a WHO growth reference for school-aged children and adolescents. *Bulletin of the World Health Organization*, *85*(9), 660–667. https://doi.org/10.2471/blt.07.043497

de Victo, E. R., Ferrari, G., Drenowatz, C., & Solé, D. (2024). Association of physical activity and sitting time with tobacco and alcohol use in 222, 495 adolescents from 66 countries. *BMC Pediatrics*, *24*(1), 596. https://doi.org/10.1186/s12887-024-05079-1

Draper, C. E., Grobler, L., Micklesfield, L. K., & Norris, S. A. (2015). Impact of social norms and social support on diet, physical activity and sedentary behaviour of adolescents: A scoping review. *Child: Care, Health and Development*, *41*(5), 654–667. https://doi.org/10.1111/cch.12241

Duffey, K., Barbosa, A., Whiting, S., Mendes, R., Yordi Aguirre, I., Tcymbal, A., Abu-Omar, K., Gelius, P., & Breda, J. (2021). Barriers and facilitators of physical activity participation in adolescent girls: A systematic review of systematic reviews [Systematic Review]. *Frontiers in Public Health*, *9*, 9. https://doi.org/10.3389/fpubh.2021.743935

Duncan, S. C., Duncan, T. E., & Strycker, L. A. (2005). Sources and types of social support in youth physical activity. *Health Psychology*, *24*(1), 3–10. https://doi.org/10.1037/0278-6133.24.1.3

Dyson, B., & Casey, A. (2016). *Cooperative learning in physical education and physical activity: A practical introduction*. Routledge.

Everett, M., & Freeman, L. (2002). *Ucinet for Windows: Software for social network analysis*. Analytic Technologies.

Fang, K., Mu, M., Liu, K., & He, Y. (2019). Screen time and childhood overweight/obesity: A systematic review and meta-analysis. *Child: Care, Health and Development*, *45*(5), 744–753. https://doi.org/10.1111/cch.12701

Gallucci, M. (2019). *Gamlj: General analyses for linear models*. https://gamlj.github.io

Gerritsen, S., Harré, S., Rees, D., Renker-Darby, A., Bartos, A. E., Waterlander, W. E., & Swinburn, B. (2020). Community group model building as a method for engaging participants and mobilising action in public health. *International Journal of Environmental Research and Public Health*, *17*(10), 3457. https://doi.org/10.3390/ijerph17103457

Gerritsen, S., Renker-Darby, A., Harré, S., Rees, D., Raroa, D. A., Eickstaedt, M., Sushil, Z., Allan, K., Bartos, A. E., Waterlander, W. E., & Swinburn, B. (2019). Improving low fruit and vegetable intake in children: Findings from a system dynamics, community group model building study. *PLOS ONE*, *14*(8), e0221107. https://doi.org/10.1371/journal.pone.0221107

Gill, M., Chan-Golston, A. M., Rice, L. N., Roth, S. E., Crespi, C. M., Cole, B. L., Koniak-Griffin, D., & Prelip, M. L. (2017). Correlates of social support and its association with physical activity among young adolescents. *Health Education & Behavior*, *45*(2), 207–216. https://doi.org/10.1177/1090198117714826

Gillison, F. B., Rouse, P., Standage, M., Sebire, S. J., & Ryan, R. M. (2019). A meta-analysis of techniques to promote motivation for health behaviour change from a self-determination theory perspective. *Health Psychology Review*, *13*(1), 110–130. https://doi.org/10.1080/17437199.2018.1534071

Guthold, R., Stevens, G., Riley, L., & Bull, F. (2020). Global trends in insufficient physical activity among adolescents: A pooled analysis of 298 population-based surveys with 1·6 million participants. *The Lancet Child & Adolescent Health*, *4*(1), 23–35. https://doi.org/10.1016/S2352-4642(19)30323-2

Hennessy, E., Economos, C. D., Hammond, R. A., Sweeney, L. B., Brukilacchio, L., Chomitz, V. R., Collins, J., Nahar, E., Rioles, N., Allender, S., Swinburn, B., Gillman, M. W., Hovmand, P., Kasman, M., & Nichols, M. (2020). Integrating complex systems methods to advance obesity prevention intervention research. *Health Education & Behavior*, *47*(2), 213–223. https://doi.org/10.1177/1090198119898649

Hills, A. P., Dengel, D. R., & Lubans, D. R. (2015). Supporting public health priorities: Recommendations for physical education and physical activity promotion in schools. *Progress in Cardiovascular Diseases*, *57*(4), 368–374. https://doi.org/10.1016/j.pcad.2014.09.010

Hoffmann, T. C., Glasziou, P. P., Boutron, I., Milne, R., Perera, R., Moher, D., Altman, D. G., Barbour, V., Macdonald, H., Johnston, M.,

Lamb, S. E., Dixon-Woods, M., McCulloch, P., Wyatt, J. C., Chan, A.-W., & Michie, S. (2014). Better reporting of interventions: Template for intervention description and replication (TIDieR) checklist and guide. *British Medical Journal*, *348*(mar07 3), g1687. https://doi.org/10.1136/bmj.g1687

Holt-Lunstad, J., Smith, T. B., & Layton, J. B. (2010). Social relationships and mortality risk: A meta-analytic review. *PLOS Medicine*, *7*(7), e1000316. https://doi.org/10.1371/journal.pmed.1000316

Hosseini Shokouh, S. M., Arab, M., Emamgholipour, S., Rashidian, A., Montazeri, A., & Zaboli, R. (2017). Conceptual models of social determinants of health: A narrative review. *Iranian Journal of Public Health*, *46*(4), 435–446.

Hovmand, P. S. (2014). Group model building and community-based system dynamics process. In P. S. Hovmand (Ed.), *Community based system dynamics* (pp. 17–30). Springer. https://doi.org/10.1007/978-1-4614-8763-0_2

Hovmand, P. S., Andersen, D. F., Rouwette, E., Richardson, G. P., Rux, K., & Calhoun, A. (2012). Group model-building 'scripts' as a collaborative planning tool. *Systems Research and Behavioral Science*, *29*(2), 179–193. https://doi.org/10.1002/sres.2105

Hu, D., Zhou, S., Crowley McHattan, Z. J., & Liu, Z. (2021). Factors that influence participation in physical activity in school-aged children and adolescents: A systematic review from the social ecological model perspective. *International Journal of Environmental Research and Public Health*, *18*(6), 3147. https://doi.org/10.3390/ijerph18063147

Hunter, R. F., de la Haye, K., Murray, J. M., Badham, J., Valente, T. W., Clarke, M., & Kee, F. (2019). Social network interventions for health behaviours and outcomes: A systematic review and meta-analysis. *PLOS Medicine*, *16*(9), e1002890. https://doi.org/10.1371/journal.pmed.1002890

Jago, R., Tibbitts, B., Willis, K., Sanderson, E., Kandiyali, R., Reid, T., Kipping, R. R., Campbell, R., MacNeill, S. J., Hollingworth, W., & Sebire, S. J. (2021). Effectiveness and cost-effectiveness of the PLAN-A intervention, a peer led physical activity program for adolescent girls: Results of a cluster randomised controlled trial. *International Journal of Behavioral Nutrition and Physical Activity*, *18*(1), 63. https://doi.org/10.1186/s12966-021-01133-8

Janssen, I., & LeBlanc, A. G. (2010). Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. *International Journal of Behavioral Nutrition and Physical Activity*, *7*(1), 2–16. https://doi.org/10.1186/1479-5868-7-40

Jones, A., Armstrong, B., Weaver, R. G., Parker, H., von Klinggraeff, L., & Beets, M. W. (2021). Identifying effective intervention strategies to reduce children's screen time: A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity*, *18*(1), 126. https://doi.org/10.1186/s12966-021-01189-6

Laird, Y., Fawkner, S., Kelly, P., McNamee, L., & Niven, A. (2016). The role of social support on physical activity behaviour in adolescent girls: A systematic review and meta-analysis. *International Journal of Behavioral Nutrition and Physical Activity*, *13*(1), 79. https://doi.org/10.1186/s12966-016-0405-7

Lewis, L., Povey, R., Rose, S., Cowap, L., Semper, H., Carey, A., Bishop, J., & Clark-Carter, D. (2021). What behavior change techniques are associated with effective interventions to reduce screen time in 0-5 year olds? A narrative systematic review. *Preventive Medicine Reports*, *23*, 101429. https://doi.org/10.1016/j.pmedr.2021.101429

Lin, H., Chen, H., Liu, Q., Xu, J., & Li, S. (2024). A meta-analysis of the relationship between social support and physical activity in adolescents: The mediating role of self-efficacy. *Frontiers in Psychology*, *14*, 1305425. https://doi.org/10.3389/fpsyg.2023.1305425

Lin, S., Faust, L., Robles-Granda, P., Kajdanowicz, T., & Chawla, N. V. (2019). Social network structure is predictive of health and wellness. *PLOS ONE*, *14*(6), e0217264. https://doi.org/10.1371/journal.pone.0217264

Lohman, T., Roche, A., & Martorell, R. (1988). *Anthropometric standardization reference manual*. Human kinetics.

Marks, J., de la Haye, K., Barnett, L., & Allender, S. (2016). Friendship network characteristics are associated with physical activity and sedentary behavior in early adolescence. *PLOS ONE*, *10*(12), e0145344. https://doi.org/10.1371/journal.pone.0145344

Marks, P. E. L., Babcock, B., Cillessen, A. H. N., & Crick, N. R. (2013). The effects of participation rate on the internal reliability of peer nomination measures. *Social Development*, *22*(3), 609–622. https://doi.org/10.1111/j.1467-9507.2012.00661.x

Martins, J., Costa, J., Sarmento, H., Marques, A., Farias, C., Onofre, M., & Valeiro, M. G. (2021). Adolescents' perspectives on the barriers and facilitators of physical activity: An updated systematic review of qualitative studies. *International Journal of Environmental Research and Public Health*, *18*(9), 4954. https://doi.org/10.3390/ijerph18094954

McLeroy, K. R., Bibeau, D., Steckler, A., & Glanz, K. (1988). An ecological perspective on health promotion programs. *Health Education Quarterly*, *15*(4), 351–377. https://doi.org/10.1177/109019818801500401

Meadows, D. H. (2008). *Thinking in systems*. Chelsea green publishing.

Mendonça, G., Cheng, L. A., Mélo, E. N., & de Farias Júnior, J. C. (2014). Physical activity and social support in adolescents: A systematic review. *Health Education Research*, *29*(5), 822–839. https://doi.org/10.1093/her/cyu017

Moher, D., Hopewell, S., Schulz, K. F., Montori, V., Gøtzsche, P. C., Devereaux, P. J., Elbourne, D., Egger, M., & Altman, D. G. (2012). Consort, 2010 explanation and elaboration: Updated guidelines for reporting parallel group randomised trials. *International Journal of Surgery*, *10*(1), 28–55. https://doi.org/10.1016/j.ijsu.2011.10.001

Nascimento-Ferreira, M. V., De Moraes, A. C. F., Toazza-Oliveira, P. V., Forjaz, C. L. M., Aristizabal, J. C., Santaliesra-Pasías, A. M., Lepera, C., Nascimento-Junior, W. V., Skapino, E., Delgado, C. A., Moreno, L. A., & Carvalho, H. B. (2018). Reliability and validity of a questionnaire for physical activity assessment in South American children and adolescents: The SAYCARE study. *Obesity*, *26*(S1), S23–S30. https://doi.org/10.1002/oby.22116

Neil-Sztramko, S. E., Caldwell, H., & Dobbins, M. (2021). School-based physical activity programs for promoting physical activity and fitness in children and adolescents aged 6 to 18. *Cochrane Database of Systematic Reviews(9)*, *2021*(9). https://doi.org/10.1002/14651858.CD007651.pub3

Norman, G. J., Schmid, B. A. A., Sallis, J. F., Calfas, K. J., & Patrick, K. (2005). Psychosocial and environmental correlates of adolescent sedentary behaviors. *Pediatrics*, *116*(4), 908–916. https://doi.org/10.1542/peds.2004-1814

Petro-Petro, J., Arango-Paternina, C., Patiño-Villada, F. A., Ramirez-Villada, J. F., & Brownson, R. C. (2024). Implementation processes of social network interventions for physical activity and sedentary behavior among children and adolescents: A scoping review. *BMC Public Health*, *24*(1), 1101. https://doi.org/10.1186/s12889-024-18615-6

Pettee Gabriel, K. K., Morrow, J. R., & Woolsey, A.-L. T. (2012). Framework for physical activity as a complex and multidimensional behavior. *Journal of Physical Activity and Health*, *9*(s1), S11–S18. https://doi.org/10.1123/jpah.9.s1.s11

Pirasteh, A., Hidarnia, A., Asghari, A., Faghihzadeh, S., & Ghofranipour, F. (2008). Development and validation of psychosocial determinants measures of physical activity among Iranian adolescent girls. *BMC Public Health*, *8*(1), 150. https://doi.org/10.1186/1471-2458-8-150

Pocock, S. J. (2013). *Clinical trials: A practical approach*. John Wiley & Sons.

Prochnow, T., Delgado, H., Patterson, M. S., & Umstattd Meyer, M. R. (2020). Social network analysis in child and adolescent physical activity research: A systematic literature review. *Journal of Physical Activity and Health*, *17*(2), 1–11. https://doi.org/10.1123/jpah.2019-0350

Proestakis, A., DiSorrentino, E. P., Brown, H. E., van Sluijs, E., Mani, A., Caldeira, S., & Herrmann, B. (2018). Network interventions for changing physical activity behaviour in preadolescents. *Nature Human Behaviour*, *2*(10), 778–787. https://doi.org/10.1038/s41562-018-0436-y

Robbins, L. B., Ling, J., Dalimonte-Merckling, D. M., Sharma, D. B., Bakhoya, M., & Pfeiffer, K. A. (2018). Sources and types of social support for physical activity perceived by fifth to eighth grade girls. *Journal of Nursing Scholarship*, *50*(2), 172–180. https://doi.org/10.1111/jnu.12369

Robbins, L. B., Wen, F., & Ling, J. (2019). Mediators of physical activity behavior change in the "girls on the move" intervention. *Nursing*

Research, *68*(4), 257–266. https://doi.org/10.1097/nnr.0000000000000359

Rodriguez-Ayllon, M., Cadenas-Sánchez, C., Estévez-López, F., Muñoz, N. E., Mora-Gonzalez, J., Migueles, J. H., Molina-García, P., Henriksson, H., Mena-Molina, A., Martínez-Vizcaíno, V., Catena, A., Löf, M., Erickson, K. I., Lubans, D. R., Ortega, F. B., & Esteban-Cornejo, I. (2019). Role of physical activity and sedentary behavior in the mental health of preschoolers, children and adolescents: A systematic review and meta-analysis. *Sports Medicine*, *49*(9), 1383–1410. https://doi.org/10.1007/s40279-019-01099-5

Ryan, R. M., & Deci, E. L. (2017). *Self-determination theory: Basic psychological needs in motivation, development, and wellness*. Guilford Publications.

Sallis, J. F., Cervero, R. B., Ascher, W., Henderson, K. A., Kraft, M. K., & Kerr, J. (2006). An ecological approach to creating active living communities. *Annual Review of Public Health*, *27*(1), 297–322. https://doi.org/10.1146/annurev.publhealth.27.021405.102100

Sallis, J. F., Prochaska, J. J., & Taylor, W. C. (2000). A review of correlates of physical activity of children and adolescents. *Medicine & Science in Sports & Exercise*, *32*(5), 963–975. https://doi.org/10.1097/00005768-200005000-00014

Sallis, J. F., Taylor, W. C., Dowda, M., Freedson, P. S., & Pate, R. R. (2002). Correlates of vigorous physical activity for children in grades 1 through 12: Comparing parent-reported and objectively measured physical activity. *Pediatric Exercise Science*, *14*(1), 30–44. https://doi.org/10.1123/pes.14.1.30

Sawka, K. J., McCormack, G. R., Nettel-Aguirre, A., Blackstaffe, A., Perry, R., & Hawe, P. (2014). Associations between aspects of friendship networks, physical activity, and sedentary behaviour among adolescents. *Journal of Obesity*, *2014*(12), 632689. https://doi.org/10.1155/2014/632689

Sawka, K. J., McCormack, G. R., Nettel-Aguirre, A., Hawe, P., & Doyle-Baker, P. K. (2013). Friendship networks and physical activity and sedentary behavior among youth: A systematized review. *International Journal of Behavioral Nutrition & Physical Activity*, *10*(1), 130. https://doi.org/10.1186/1479-5868-10-130

Sebire, S. J., Jago, R., Banfield, K., Edwards, M. J., Campbell, R., Kipping, R., Blair, P. S., Kadir, B., Garfield, K., Matthews, J., Lyons, R. A., & Hollingworth, W. (2018). Results of a feasibility cluster randomised controlled trial of a peer-led school-based intervention to increase the physical activity of adolescent girls (PLAN-A). *International Journal of Behavioral Nutrition and Physical Activity*, *15*(1), 50. https://doi.org/10.1186/s12966-018-0682-4

Siedentop, D., Hastie, P., & Van der Mars, H. (2011). *Complete guide to sport education*. Human Kinetics.

Smilkstein, G. (1978). The family APGAR: A proposal for a family function test and its use by physicians. *Journal of Family Practice*, *6*(6), 1231–1239.

Smit, C. R., de Leeuw, R. N. H., Bevelander, K. E., Burk, W. J., Buijs, L., van Woudenberg, T. J., & Buijzen, M. (2021). Promoting water consumption among children: A three-arm cluster randomised controlled trial testing a social network intervention. *Public Health Nutrition*, *24*(8), 2324–2336. https://doi.org/10.1017/S1368980020004802

Sterdt, E., Liersch, S., & Walter, U. (2014). Correlates of physical activity of children and adolescents: A systematic review of reviews. *Health Education Journal*, *73*(1), 72–89. https://doi.org/10.1177/0017896912469578

Sterman, J. (2000). *Business dynamics*. McGraw-Hill, Inc.

Tarp, J., Dalene, K. E., Fagerland, M. W., Steene-Johannesen, J., Hansen, B. H., Anderssen, S. A., Hagströmer, M., Dohrn, I.-M., Dempsey, P. C., Wijndaele, K., Brage, S., Nordström, A., Nordström, P., Diaz, K. M., Howard, V. J., Hooker, S. P., Morseth, B., Hopstock, L. A., Sagelv, E. H. … Ekelund, U. (2024). Physical activity volume, intensity, and mortality: Harmonized meta-analysis of prospective cohort studies. *American Journal of Preventive Medicine*, 1–10. https://doi.org/10.1016/j.amepre.2024.07.022

Tock, W. L., Gauvin, L., Hudon, F., Tremblay, F., Bélanger, R. E., & Turcotte-Tremblay, A.-M. (2025). Scoping review of interventions aimed at promoting healthy screen use among adolescents. *BMJ Open*, *15*(9), e103772. https://doi.org/10.1136/bmjopen-2025-103772

Valente, T. W. (2010). *Social networks and health: Models, methods, and applications*. Oxford University Press.

Valente, T. W. (2012). Network interventions. *Science*, *337*(6090), 49–53. https://doi.org/10.1126/science.1217330

van Woudenberg, T. J., Bevelander, K. E., Burk, W. J., Smit, C. R., Buijs, L., & Buijzen, M. (2018). A randomized controlled trial testing a social network intervention to promote physical activity among adolescents. *BMC Public Health*, *18*(1), 542. https://doi.org/10.1186/s12889-018-5451-4

van Woudenberg, T. J., Bevelander, K. E., Burk, W. J., Smit, C. R., Buijs, L., & Buijzen, M. (2020). Testing a social network intervention using vlogs to promote physical activity among adolescents: A randomized controlled trial. *Frontiers in Psychology*, *10*. https://doi.org/10.3389/fpsyg.2019.02913

Vieira, V. D. S., Aguiar, S. D. C., Campos, M. C., Fontanela, L. C., Canever, J. B., Hauck, M., Do Amaral, L. A., Cáceres, V. D. M., Schneider, I. J. C., & Vieira, D. S. R. (2024). Light-intensity physical activity and sedentary behavior are associated with blood pressure levels in adolescents. *Pediatric Exercise Science*, 1–9. https://doi.org/10.1123/pes.2023-0120

Wilcox, R. R. (2022). *Introduction to robust estimation and hypothesis testing* (5th ed.). Academic press.

Wu, X., Han, L., Zhang, J., Luo, S., Hu, J., & Sun, K. (2017). The influence of physical activity, sedentary behavior on health-related quality of life among the general population of children and adolescents: A systematic review. *PLOS ONE*, *12*(11), e0187668. https://doi.org/10.1371/journal.pone.0187668