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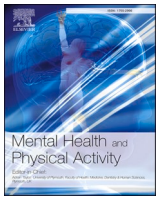

Modifiable determinants of adolescents' physical activity and sedentary behaviour in school, home and mixed settings: A DE-PASS systematic review and meta-analysis of self-reported data with a holistic analysis

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ABSTRACT

Purpose: Despite physical activity (PA)'s health benefits, few adolescents meet recommended levels. This review examined associations between adolescents' self-reported PA and sedentary behaviours (SB) and their modifiable determinants, assessing interventions across settings (school, home, mixed).
Methods: Five databases were searched from 2010 to 2023. Eligible studies included experimental studies assessing adolescents' self-reported PA/SB and modifiable determinants at pre- and post-intervention. Within a social-ecological framework, Robust-Bayesian-Meta-Analyses (RoBMA) were conducted per setting, assessing heterogeneity and publication-bias. Single-study outcomes were narratively reported. A holistic classification of determinant domains was then applied to map measured determinants and targeted intervention components across individual-psychological, individual-behavioural, interpersonal, and environmental domains. Risk of bias and evidence certainty were also evaluated. PROSPERO-ID: CRD42021282874.
Results: Twelve RCTs and two CTs (school $n = 10$, home $n = 2$, and school-home $n = 2$ settings) were included. Thirteen studies (93%) incorporated theory-based approaches, and 13 studies (93%) addressed multiple determinant domains, although only four (29%) showed high-integration multi-domain designs. Of the 67 unique modifiable determinants identified, 94% were classified within individual/interpersonal categories. In particular, RoBMAs showed minimal or no pooled effects on PA/SB or determinants, except for weak evidence suggesting a small positive effect on planning in school setting, including action and coping planning, implementation intentions, or commitment to a plan of action, with substantial heterogeneity across studies. Risk of bias was due mainly to randomization and outcome measurement issues. The level of certainty from the evidence ranged from very low to low.
Discussion: Existing interventions predominantly target individual-level factors, with limited coordinated integration across socio-ecological domains. High-quality future trials should test whether well-designed, integrated multilevel interventions can more consistently modify diverse determinants of adolescents' PA/SB across setting and co-occur with psychosocial benefits.

1. Introduction

Adolescence represents a developmental phase in which lifelong health behaviours begin to consolidate. During this period, physical activity (PA, i.e., any bodily movement produced by skeletal muscles that requires energy expenditure) plays a fundamental role in supporting overall well-being. In fact, regular PA is linked to numerous health benefits, including improved cognitive performance, academic outcomes, and mental well-being such as affect regulation, perceived competence, self-esteem and body image (Aubert et al., 2021; Biddle et al., 2019; Diamond & Ling, 2020; Rodriguez et al., 2020). Importantly, several determinants commonly targeted in PA interventions, including motivation, affective responses, perceived competence, social support and body-related perceptions are central constructs within contemporary models of adolescent mental health. Although these constructs should not be equated with clinical or psychosocial outcomes unless such outcomes are directly assessed, PA and psychological functioning may develop interdependently: mental health-related determinants can influence adolescents' engagement in PA, while participation in PA may, in turn, affect psychological functioning. This bidirectional relationship underscores the need to understand modifiable determinants within an integrated framework (Biddle et al., 2019; Ekkekakis & Brand, 2021; Lubans et al., 2016; Pesce et al., 2021).

Despite the established benefits of PA, insufficient PA and high levels of sedentary behaviour (SB, i.e., $\leq$1.5 METs while waking) remain prevalent among adolescents worldwide. Fewer than 20 percent meet international recommendations for daily moderate-to-vigorous PA, and inadequate activity levels are associated with increased risks of obesity, cardiometabolic conditions and poorer psychological well-being (Ding et al., 2016; van Sluijs et al., 2021; World Health Organization. Regional Office for Europe, 2022). European and international policy documents consistently highlight the importance of developing effective strategies to address these trends by acting on modifiable determinants of PA and SB across relevant settings, including schools, homes and communities (Brug et al., 2017; Bull et al., 2020; Chastin et al., 2016; Condello et al., 2016; Puggina et al., 2017; WHO Regional Office for Europe, 2021; World Health Organization, 2019). However, these health-enhancing PA policies must be informed by high-quality research on modifiable determinants of adolescents' PA across different social and environmental contexts (Carlin et al., 2017; World Health Organization, 2022). Within this context, the Cost Action DEterminants of Physical Activity in SettingS (DE-PASS; CA19101 [https://depass.eu/]) was established as a European research network aiming to identify, understand, and measure modifiable determinants of physical activity and sedentary behaviours across the life course and in different settings. Specifically, DE-PASS adopts a social-ecological perspective that considers individual, interpersonal, organisational, community and environmental influences on movement behaviours (Ciaccioni et al., 2025; Dygryn et al., 2025; Fusco et al., 2026; Khudair, et al., 2022, 2024; Kolovelonis et al., 2024; Ling et al., 2024; Palmeira et al., 2024).

Previous systematic and umbrella reviews (Aleksovska et al., 2019; Chastin et al., 2015; Condello et al., 2017; Cortis et al., 2017; Holdsworth et al., 2017; Jaeschke et al., 2017; Lakerveld et al., 2014; Loyen et al., 2016; O'Donoghue et al., 2018; Stierlin et al., 2015) have provided important insights into determinants of PA and SB with single domain analyses, focusing separately on psychological, social or environmental factors. This domain-specific approach has generated a fragmented understanding of mechanisms, despite theoretical frameworks emphasising that adolescents' PA is shaped by dynamic interactions among multiple levels of influence. Evidence remains limited regarding the extent to which interventions simultaneously target determinants across domains, and whether changes in psychological, behavioural and social constructs co-occur in a manner consistent with integrated models of behaviour change, such as social–ecological frameworks, Self-Determination Theory, or COM-B–based approaches, which explicitly posit interacting multilevel mechanisms. Moreover, the review outcomes have been mixed and inconclusive, largely due to methodological variability (e.g., in PA measurements) and moderate studies' quality. This systematic review and meta-analysis (SRMA)

focuses on randomized controlled trials (RCTs) and controlled trials (CTs) because these designs are best suited to examine causal effects of interventions targeting modifiable determinants on adolescents' PA and SB. In fact, RCTs are considered the methodological gold standard for establishing causal inferences, whereas CTs provide a viable alternative when randomization is not feasible due to ethical, logistical or contextual constraints (Higgins et al., 2023). Moreover, self-reported measures of PA and SB are widely used in adolescent research because they allow researchers to capture behaviours, perceptions and contextual information that are not easily obtainable through device-based methodologies (Sallis, Cerin, et al., 2016). These instruments are practical to administer across diverse settings and can provide insights into activity types, domains and motivations that complement objective measurements (Ciaccioni et al., 2025; Lubans et al., 2011). Whilst interest in adolescent PA is growing, further studies are crucial to clarify PA decline in adolescence (Guthold et al., 2020), identify PA/SB barriers and facilitators (Martins et al., 2021), and inform interventions and policies (Bull et al., 2020). With a focus on self-reported PA/SB, this study offers valuable insights into modifiable determinants and settings to effectively enhance PA or reduce SB in adolescents, contributing to public health policy (Piercy et al., 2018; World Health Organization, 2020).

Thus, the present SRMA aims to: (i) identify modifiable determinants investigated in randomized and controlled trials; (ii) assess the effects of the interventions on PA, SB and the targeted determinants; and (iii) explore potential associations between determinant changes and adolescents' PA or SB across settings. Beyond quantifying intervention effects, the review also mapped how determinants clustered across psychological, behavioural and interpersonal domains and evaluated whether interventions addressed these domains jointly or in isolation. Given the interdependent development of PA and mental-health related determinants during adolescence, such an approach provides a more comprehensive understanding of the mechanisms that may underlie changes in PA, SB and associated psychosocial constructs.

2. Methods

2.1. Protocol, registration and set-up

A standardized protocol for all systematic reviews and meta-analyses (SRMAs) focusing on children and adolescents, conducted as part of the DE-PASS consortium, was registered with the International Prospective Register of Systematic Reviews (PROSPERO) on October 12, 2021, under registration number CRD42021282874, and was subsequently published (Khudair et al., 2022). This study and its protocol (Khudair et al., 2022; Page et al., 2021) follow the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Supplementary file 1). All reviewers involved in screening, data extraction, and risk of bias assessment and evidence certainty attended relevant workshops to ensure efficiency, mutual understanding, and consistency. Continuous communication among reviewers was maintained throughout the process. Formal inter-rater reliability coefficients were not calculated for study screening, eligibility assessment, and data extraction. However, consistency across reviewers was promoted through reviewer training, dual independent assessment, structured screening and extraction forms, consensus meetings, and third-reviewer adjudication when required.

2.2. Eligibility criteria

Eligible studies had to meet the following criteria: a) include adolescents (13-19 years inclusive) without medical conditions affecting PA; b) use RCT/CT design with interventions promoting PA and/or reducing SB and a control or comparison group; c) report PA/SB as an outcome; d) use self-report methods to measure PA/SB; e) assess modifiable determinants of PA/SB at least two time-points; f) measure both PA/SB and determinants at least at pre- and post-intervention; and g) be published in a peer-reviewed journals after 2010, when the WHO issued the first global PA guidelines (World Health Organization, 2010). All forms of PA (e.g., physical education, exercise, sport, active transport) and SB (e.g., screen time, transport-related, leisure-based) were included. No specific intervention duration was required. Studies with broader age ranges were excluded unless subgroup data for 13-19-year--olds were provided. Grey literature was excluded, and non-English studies were included if translation was available.

2.3. Search strategy

A search was conducted in PsycINFO, MEDLINE, Web of Science, Sport Discus, and Cochrane CENTRAL from January 2010 to September 2021, and updated in July 2023. Search terms included: a) PA, b) SB, c) RCT, d) CT, e) determinants in PA research, f) adolescents, and g) self-reported PA/SB measurement methods (e.g., questionnaires, surveys, scales). Synonyms and related terms relevant to PA/SB research were also included in the search string. Full details on search terms and Boolean commands are available in the study protocol paper (Khudair et al., 2022).

2.4. Screening process

The review team initially screened records using EndNote x9 (Clarivate, 2020) to exclude grey literature and duplicates. The filtered studies were uploaded to Covidence (Veritas Health Innovation, 2024) to enable independent assessment by multiple reviewers. Screening was conducted in two blinded stages: title/abstract and full-text. Each study was assessed by two independent, randomly assigned reviewers, with a third reviewer resolving conflicts, if needed. A decision tree guided the inclusion/exclusion criteria, and reasons for full-text exclusions were documented. Finally, the included studies were examined for duplicate reporting (Page et al., 2021).

2.5. Data extraction

Whilst two independent reviewers extracted data using a Covidence form, conflicts between them were resolved through consensus meetings. Missing data were requested from corresponding authors and studies with incomplete data were excluded. Extracted data included study details, intervention descriptions, participant information, PA/SB measures, modifiable determinants, study time frames, and results (Khudair et al., 2022).

2.6. Holistic determinant classification

In addition to extracting intervention characteristics and measured modifiable determinants, an holistic classification was applied based on the social–ecological framework (Kilanowski, 2017). This classification distinguished between: (i) intervention components targeted by the intervention design, and (ii) determinants measured as pre-post outcomes. This distinction was necessary because some interventions included environmental or organisational components, such as modifications to school spaces, access to equipment, structured opportunities during school time, home-based prompts, digital resources, or family media rules, but did not measure environmental or organisational determinants as outcomes.

Each measured determinant was classified into one of four domains: individual-psychological, individual-behavioural, interpersonal, and environmental. Individual-psychological determinants included constructs such as motivation, self-efficacy, perceived competence, body appreciation, attitudes, intentions, and affect-related variables. Individual-behavioural determinants included constructs such as planning, self-monitoring, and behavioural regulation. Interpersonal determinants included family, peer, teacher, mentor, or parent support. Environmental determinants were defined as measurable features of the

physical, organisational, digital, or home environment that could plausibly influence adolescents' physical activity or sedentary behaviour.

The holistic classification was piloted on a subset of included studies to refine coding rules and support a consistent distinction between intervention components targeted and determinants measured. Two reviewers independently coded the presence or absence of each determinant domain for each included study before consensus. Because each study could include more than one domain, the coding was treated as a set of binary domain-level judgements. Inter-rater reliability was assessed using Cohen's kappa and percentage agreement separately for the individual-psychological, individual-behavioural, interpersonal, and environmental domains. Disagreements were resolved through consensus discussion and, when required, consultation with a third reviewer. To characterise the extent of holistic integration, each intervention was classified as single-domain, low-integration multidomain, moderate-integration multidomain, or high-integration multidomain (Stodden et al., 2023; Stodden & Pesce, 2025). High-integration designs were defined as interventions that intentionally coordinated mechanisms across several domains within a coherent theoretical or implementation framework. Moderate-integration designs combined more than one domain but showed limited evidence that the domains were explicitly coordinated. Low-integration multi-domain designs included components from more than one domain but with minimal theoretical or operational linkage between them. Single-domain designs targeted only one determinant domain.

Only constructs measured at pre– and post-intervention were eligible for quantitative synthesis as modifiable determinants. Consequently, environmental components could be coded as part of the intervention profile but were not included as measured determinants unless they were operationalised and assessed as pre-post outcomes. This procedure allowed us to identify the gap between holistic intervention design and determinant measurement. For each study, the co-occurrence of targeted components and measured determinants across domains was documented and examined narratively to explore whether multidomain intervention designs aligned with changes in PA or SB. This analytic step complemented the primary quantitative synthesis by providing an integrated perspective on how interventions may influence adolescents' movement behaviours through interacting mechanisms across domains, while also acknowledging the current measurement gap regarding environmental and organisational determinants (Stodden et al., 2023; Stodden & Pesce, 2025).

2.7. Risk of bias

The risk of bias was evaluated using the modified Cochrane tools (RoB 2.0 for randomized trials, ROBINS-I for non-randomized studies), adding a domain for determinant measurement bias (Higgins et al., 2023). Two independent data extractors conducted the RoB assessment using a Covidence form; emerging discrepancies were resolved by consensus, or, if needed, by involving a third reviewer.

2.8. Data synthesis and statistical analysis

The primary outcomes were adolescents' self-reported PA/SB (e.g., questionnaires, activity diaries and recall-based surveys) and modifiable PA/SB determinants. Total daily PA/SB was prioritized, or the closest habitual measure (e.g., MVPA/day) was used if unavailable. Conceptually related determinants were combined (e.g., intrinsic motivation and integrated regulation were collectively classified as autonomous motivation). Psychological needs (autonomy, competence, relatedness) were merged as basic psychological needs (Ryan & Deci, 2020); similar constructs (e.g., self-efficacy, confidence) were analysed under self-efficacy. Composite scores of outcomes were calculated following Borenstein et al. (Supplementary file 2), with sensitivity analysis applied to test robustness of our findings (Borenstein et al., 2021).

The outcomes related to PA and SB, as well as their determinants, were analysed according to the study setting, when at least two studies addressed the same outcome within that context. Determinants were evaluated independently of PA/SB outcomes. Results from outcomes reported by a single study were presented narratively. When studies reported distinct outcomes for habitual and non-habitual PA, these were treated as separate effect sizes. For studies including multiple intervention arms or assessing more than one determinant, each relevant comparison was extracted and allocated to the corresponding meta-analysis, avoiding double-counting of participants. Follow-up measurements were categorized into short-term ($\leq$6 months) and long-term (>6 months) periods and analysed accordingly, excluding mid-intervention assessments.

The standardized mean difference (SMD) and standard error were calculated for all outcomes, analysed either narratively or via MA, which were conducted using JASP 0.19.1, employing Robust-Bayesian-Meta-Analysis (RoBMA) with the RoBMA R package and Markov Chain Monte Carlo algorithms in JAGS (Bartos et al., 2023; Jasp Team, 2024; Maier et al., 2023; Plummer, 2017). Only the random-effects component of RoBMA, comprising 18 models with default priors, was used (Bartos et al., 2023). Bayes factors (BF_{10}) were used to evaluate both intervention effects and publication bias. Following Lee and Wagenmakers' interpretive framework, $BF_{10} > 1$ indicates evidence supporting an effect, values between 0.33 and 1 are considered inconclusive, and $BF_{10} < 0.10$ provides evidence in favour of the null hypothesis (Lee & Wagenmakers, 2014) (Supplementary file 3 for cut-off criteria for the interpretation of BF_{10}). Cohen's d with 95% credible intervals (CI) was reported, with thresholds of 0.20 (small), 0.50 (moderate), and 0.80 (large). Between-study heterogeneity was measured by τ. Classical random-effects MAs were also conducted, detailed in Supplementary file 4.

2.9. Certainty of evidence

The certainty of evidence for each outcome was assessed using the Grading Recommendations to Assess Development and Evaluation system (GRADE) system (Brozek et al., 2021), which classifies evidence into four levels: high, moderate, low, and very low. Factors affecting quality include risk of bias, imprecision, inconsistency, indirectness, and publication bias. Two independent reviewers evaluated the evidence, resolving discrepancies through consensus, with a third reviewer consulted if needed.

3. Results

3.1. Study selection

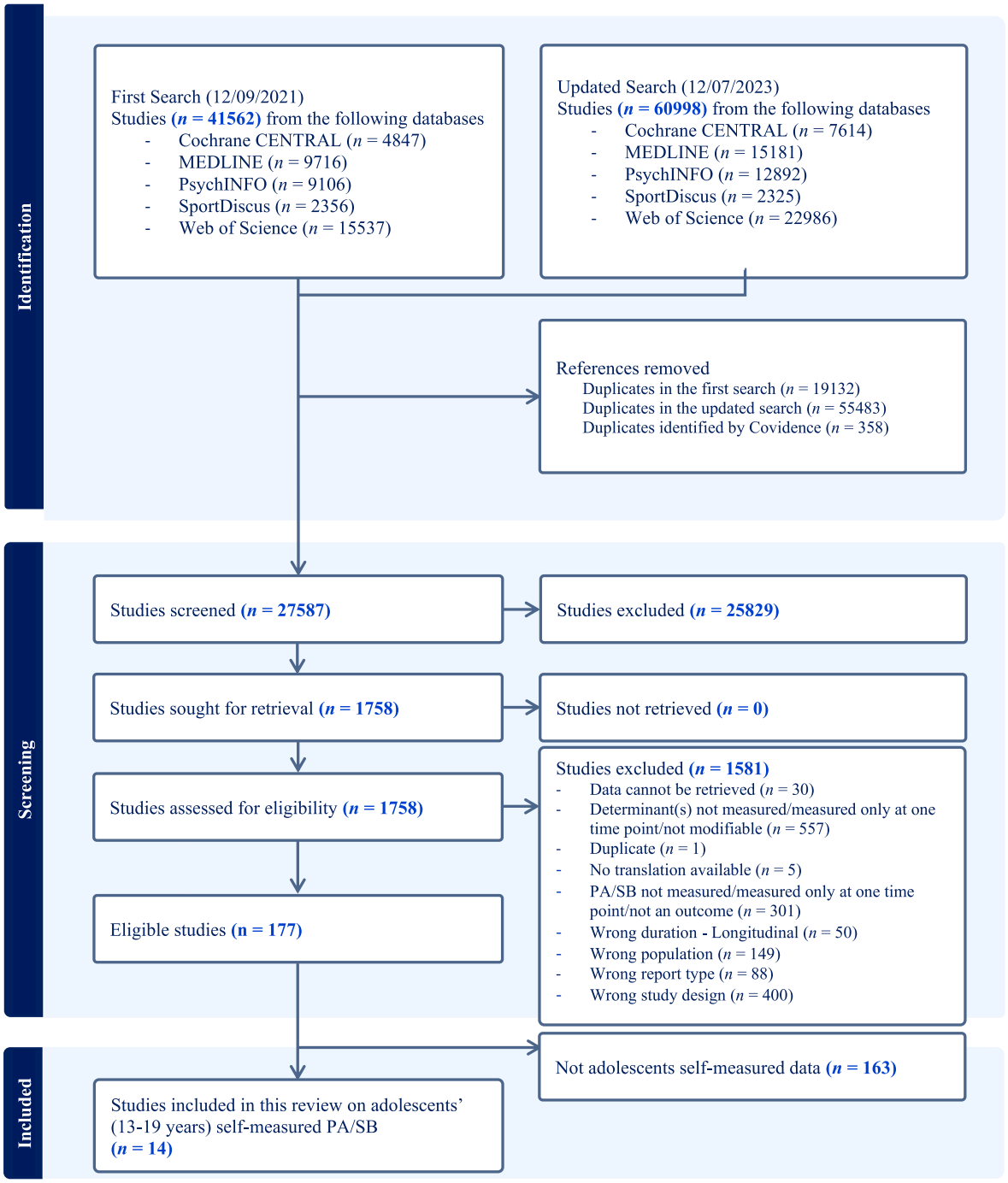
60,998 records (41,562 from the initial search) were identified from electronic databases. After removing duplicates, 27,587 records proceeded to screening. Title and abstract screening yielded 1758 full-text articles, from which 177 studies were eligible for all DE-PASS reviews on children and adolescents, including RCT, CT, and longitudinal studies (Fig. 1). This review includes 14 studies (12 RCTs and two CT) on adolescents' self-report PA/SB measurement and modifiable determinants (Page et al., 2021).

3.2. Study characteristics

Table 1 summarizes the characteristics of the analysed records, which included 6052 adolescents (60% girls), ranging from 42 to 1550 participants in the individual studies.

3.2.1. Settings

Home (two studies), school (10 studies), and school and home (two studies) were the three types of settings that emerged in the 12 RCTs (Ahmed et al., 2022; Aittasalo et al., 2019; Bronikowski et al., 2016;



N = number; *PA* = physical activity; *SB* = sedentary behaviours.

Fig. 1. PRISMA flowchart of the literature search and screening.

Bronikowski et al., 2018; Cowley et al., 2021; da Silva Bandeira et al., 2020; Dewar et al., 2014; Hankonen et al., 2017; Moreno et al., 2021; Sanaeinasab et al., 2012; Schnider et al., 2022; Whittemore et al., 2013) and the two CTs (González-Cutre et al., 2018; Grasten et al., 2017) included in the present research.

3.2.2. Determinants

In total, 67 unique modifiable determinants were identified in the 14 studies. According to the social-ecological perspective (Sallis et al., 2006), most of them were classified as individual–psychological (n = 39), some as interpersonal (n = 24) and very few were individual–behavioural (n = 4). After grouping closely related factors into broader categories, 49 determinants were analysed (25 individual–psychological, 20 interpersonal, and 4 individual–behavioural). Four of these determinants appeared in two or more studies conducted in the school setting and were included in the meta-analysis, while those identified in only one study were reported narratively.

3.2.3. Physical Activity and sedentary behaviour outcomes

Twelve RCTs (Ahmed et al., 2022; Aittasalo et al., 2019; Bronikowski et al., 2016; Bronikowski et al., 2018; Cowley et al., 2021; da Silva Bandeira et al., 2020; Dewar et al., 2014; Hankonen et al., 2017; Moreno et al., 2021; Sanaeinasab et al., 2012; Schnider et al., 2022; Whittemore et al., 2013) and two CTs (González-Cutre et al., 2018;

Table 1
Summary of randomised controlled trials (RCT) and controlled trials (CT) on adolescents' physical activity- and sedentary behaviour-related interventions.

N	1st Author Country Year[#] Study design	SS (%F) Age: year*	Setting	Intervention [Time: weeks]: description	Comparison	Determinants	PA/SB measures	PA/SB self-report measures	Outcomes	Holistic Determinant Classification
1	Ahmed -Bangladesh 2022 RCT	N = 320 (41%) 14.3 (±1.15)	School (high)	IG [8, 12]: weekly supervised circuit exercise (30 min/ week), health education session (10 min/week) with health educational materials, and lunchtime sports activities (20 min/ week)	CG: Usual care	Physical Activity Knowledge Score; Sedentary Behaviour Knowledge Score	SR-PA	IPAQ-A, modified (validated in Asian adolescents); ASAQ; PA/SB knowledge: study-specific self-report items created (no prior validation reported)	IG vs CG: ↑PA, ↓ Total ScT, ↓ScT (weekdays), ↓ ScT (weekend), = Leisure-time PA, ↓ Transport-related PA, school-based PA (↑8 weeks, ↓12 weeks), ↑home-based PA, ↑PA-KS, ↑SB-KS	**Multi-domain, low integration** (Behavioural + environmental + knowledge-based psychological; minimal interpersonal; no motivation/ affect/competence mechanisms)
2	Aittasalo -Finland 2019 RCT	N = 1550 (46%) 13.9 (±0.5)	secondary school/ family	IG [4]: multimodal, behavioral theory-driven HE lessons.	CG: standard HE lessons on PA	Intention; Family norm; Confidence of intention (walking/cycling to school, leisure PA, > 2h of screen time)	SR-PA	HBSC-format PA & screen-time items from national school surveys (previous reliability/validity shown)	IG vs CG: ↑PA, ↑intention(=walking/cycling to school, = >2h of screen time, ↓ leisure PA); Family norm (=walking/cycling to school, ↑> 2h of screen time, = leisure PA); Confidence of intention (↑ walking/ cycling to school; = leisure PA; = >2h of screen time)	**Multi-domain, moderate integration** (Psychological–behavioural core; interpersonal + environmental support)
3	Bandeira – Brazil 2020 RCT	N = 1085 (48%) 13.3 (±1.3)	School	IG [16]: 4-component intervention (teacher training; support material + assistance; promote PA and < screen time; health education)	CG: one semester with the regular and conventional activities of a full-time school.	Attitude; Self-efficacy; Family support; School support	SR-SB	YRBS-based screen-time questions (Brazilian version validated); psychosocial screen-time scales (validated α 0.64-0.85 ICC 0.63-0.71)	IG vs CG: Attitude; = Self-efficacy; = Family support; = School support, = SB	**Multi-domain, moderate integration** (Psychological core; behavioural + interpersonal + environmental support).
4	Bronikowski – Poland 2016 RCT	N = 65 (47%) 17.2 (±0.2)	School (urban)	IG [8]: 10000 steps to achieve for 8 consecutive weeks	CG: No target set, do as many steps as you can and want, every day	Classmate support; Teacher support	SR-PA	Physical Activity Screening Measure (validated in original Prochaska paper); PE support scales (previously validated)	IG vs CG: = MVPA, = Classmate support; = Teacher support	**Multi-domain, low integration** (Behavioural core; interpersonal support measured; no psychological; no environmental change)
5	Bronikowski - Poland 2018 RCT	N = 65 (46%) 17.2 (±0.2)	School (secondary)	IG [8]: 10000 steps to achieve for 8 consecutive weeks	CG: No target set, do as many steps as you can and want every day	Self-efficacy; Classmate support; Teacher support	SR-PA	Self-reported teacher/classmate support in PE using previously validated scales	IG vs CG: = MVPA, ↓Classmate support, = Self-efficacy, ↓Teacher support	**Multi-domain, low integration** (Behavioural core; psychological self-efficacy and interpersonal support measured; no environmental change)
6	Cowley – United Kingdom/ Ireland 2021 RCT	N = 42 (100%) 14.2 (±1.1)	Home	IG [6]: Weekly virtual exercise sessions (30 min); mentor support; educational text messages	CG: Wait-list control group: continue with usual PA habits	PA competence; amotivation; External; Introjected; Identified; Integrated; Intrinsic; body	SR-PA SR-SB	HBSC PA/SB subscale (validated in adolescents).	IG vs CG: = MVPA, = VPAD, = VPAH, = TV viewing, = Video games,= Internet use = competence; = amotivation; = External; = Introjected; = Identified; = Integrated, Intrinsic ↑, Body appreciation ↑, self-esteem ↑	**High-integration multi-domain** (Strong psychological + behavioural + interpersonal components; moderate digital-environmental support)

(*continued on next page*)

Table 1 (*continued*)

N	1st Author Country Year[#] Study design	SS (%F) Age: year*	Setting	Intervention [Time: weeks]: description	Comparison	Determinants	PA/SB measures	PA/SB self-report measures	Outcomes	Holistic Determinant Classification
						appreciation; self-esteem				
7	Dewar - Australia 2014 RCT	N = 357 (100%) 13.2 (±0.5)	School (secondary)	IG [52]: enhanced school sport, lunch time PA sessions, interactive seminars, student handbooks, nutrition workshops, pedometers, parent newsletters and text messages	CG: wait list control group	self-efficacy, Perceived environment (home/neighborhood, school), social support (friends, family), Behavioral strategies, Outcome expectations, Outcome expectancies	SR-SB	ASAQ (validated sedentary-time instrument); previously tested PA-related social-cognitive scales (acceptable reliability).	IG vs CG: ↓ Total SB, ↓ recreational computer use = self-efficacy, =Perceived environment (home/neighborhood, school), social support (friends, family), =Behavioral strategies, =Outcome (expectations, expectancies)	**Multi-domain, moderate integration** (SCT-based psychological + behavioural + interpersonal + environmental components)
8	Gonzales-Cutre – Spain 2018 CT	N = 88 (59%) 14.67 (±0.66)	Secondary school/ family	IG [8, 26, 52]: Teaching fitness and health with motivational strategies + extracurricular PA activities	CG: Teaching unit of fitness and health	autonomy support (teacher, peer, parental); PE and PA (competence, autonomy, relatedness, intrinsic, integrated identified, introjected, external amotivation)	SR-PA SR-SB	7-PAR Spanish version (adequate reliability and validity); SDT-based psychological scales with reported reliability/construct validity. Behavioural Regulation in Exercise Questionnaire (validated sedentary-time instrument)	IG vs CG: ↑ Autonomy support (teacher, peer, parental), ↑ PE (competence, autonomy, relatedness, identified, introjected); ↑ PA (competence, autonomy, relatedness, identified, intrinsic), = PE (intrinsic, integrated, external amotivation), = PA (integrated, introjected, external amotivation)	**High-integration multi-domain** (Strong SDT-based psychological + behavioural + interpersonal + school–family environmental components)
9	Gråsten – Finland 2017 CT	N = 240 (%: NA) 14.48 (±0.99)	School (middle)	IG [56]: Civil skill program	CG: Usual care	Perceived physical competence	SR-PA	HBSC MVPA 2-item measure (criterion validity vs accelerometer; deemed "sufficiently reliable"); PSPP subscale (high composite reliability with supported validity)	IG vs CG: ↑ Perceived physical competence = MVPA	**Multi-domain, moderate integration** (Task-climate psychological + behavioural + teacher/peer interpersonal + school-environment modifications)
10	Hankonen -Finland 2017 RCT	N = 43 (78%) 18.9 (±1.7)	School (vocational)	IG [3, 4-6, 26]: 6-h group-based intervention for students, two 2-h training workshops to reduce their students' sitting in class for teachers, provision of light PA equipment in classrooms	CG: Received teaching as usual, i.e., standard curriculum	BCTs sumscore (for general BCTs), BCT sumscore (for frequencydependent BCTs)	SR-PA SR-SB	Self-reported PA and sitting (non-standard items; no validation reported); psychosocial scales (validation not stated)	IG vs CG: ↑ BCTs sumscore (for general BCTs), ↑ BCT sumscore (for frequencydependent BCTs), = PA, = SB	**High-integration multi-domain** (Strong psychological + behavioural mechanisms; structured interpersonal and school-environment support).
11	Moreno -USA 2021 RCT	N = 1520 (52%) 14.5 (±1.6)	home/ family	IG [8]: The American Academy of Pediatrics family media use plan	CG: Usual care	Media rule engagement	SR-PA	Media rule engagement scale (previously tested; high internal reliability α = 0.93);	IG vs CG: = Media rule engagement, = PA	**Single-domain intervention** (Interpersonal/media governance only), with no psychological, behavioural or environmental determinants

(*continued on next page*)

Table 1 (*continued*)

N	1st Author Country Year[#] Study design	SS (%F) Age: year*	Setting	Intervention [Time: weeks]: description	Comparison	Determinants	PA/SB measures	PA/SB self-report measures	Outcomes	Holistic Determinant Classification
								other self-report outcomes with no explicit validation statement		relevant to PA; no holistic integration
12	Sanaeinasab - Iran 2012 RCT	N = 165 (47%) 13.9 (±0.4)	School (high)	IG: Educational program based on HPM; 10 interactive sessions (1-1.5 h each) over 2 months; 2-h family workshop [8]	CG: Regular school programs	self-efficacy, perceived benefits to exercise, Activity-related affect, Competing preferences, Situational influences, Commitment to plan of action, perceived barriers to exercise, social norms, role models, social support	SR-PA	Multiple validated self-report PA and psychosocial scales (translated and pilot-tested; internal consistency 0.76–0.85); situational influences scale translated but no prior Farsi validation	IG vs CG: **Boys** ↓ Benefits of PA, ↓ Self-efficacy, ↓ Commitment to action plan, ↑ Social norms, ↓ Social support, ↓ Weekly PA **Girls** ↑ Benefits of PA, ↑ Self-efficacy, ↑ Commitment to action plan, ↓ Social norms, ↑ Social support, ↑ Weekly PA **Both Boys and Girls** ↑ Barriers of PA, ↑ Competing preferences, ↑ Activity-related affect, ↓ Role models, ↑Situational influences	**High-integration multi-domain** (Extensive HPM psychological targets + behavioural regulation + interpersonal support + situational/environmental components).
13	Schnider -Switzerland 2022 RCT	N = 128 (52%) 14 - 19 (sd: not available)	School (middle)	IG [6]: 90-min double physical education lesson (3 sessions in 6 weeks)	CG: conventional PE lessons, (I: 45min + II: 90 min lesson per week)	Exercise/sport intention; Motivation (Intrinsic; Identified, Introjected, Extrinsic); Implementation intentions; Coping planning; Self-efficacy (barrier coping)	SR-PA	Validated self-report instruments replicated from the original trial; includes 7-PAR (validated tool) and standard psychosocial scales with reported reliability	IG vs CG: = Exercise/Sport Intention, ↓ (intrinsic, identified) motivation, ↑ extrinsic Motivation = intojected motivation, = Implementation Intentions, ↑ Coping Planning, = Self-Efficacy (Barrier Coping), = MVPA	**Multi-domain, moderate integration** (Psychological–behavioural skill training with limited peer-based interpersonal support; no environmental change).
14	Whittemore – USA 2013 RCT	N = 384 (62%) 15.31 (±0.69)	School (high)	IG [13, 26]: Internet-based obesity prevention program + coping skill component	CG: Internet-based obesity prevention program, no coping skill component	PA self-efficacy	SR-PA	Self-reported PA (Youth Risk Behaviors Survey), sedentary behaviour, diet (After School Student Questionnaire), and self-efficacy (standard items; validation not explicitly reported).	IG vs CG: ↑ PA self-efficacy, ↑ VE, ME (↑ H&TCST, = H&T), = Muscle strengthening	**Multi-domain, moderate integration** (Behavioural skills + self-efficacy + coping training + coach/peer support + structured digital environment).

Note: *ASAQ* Adolescent Sedentary Activity Questionnaire, *CG* comparison group, *DB* device-based, *HBSC* Health Behaviour in School-aged Children, *HE* Health Education, *IG* intervention Group, *IPAQ-A* International Physical Activity Questionnaire for Adolescents, *KS* - Knowledge Score, *MVPA* moderate-to-vigorous intensity physical activity, *N* number, *NA* not available, *PA* - Physical Activity, *PAM* - Physical Activity Monitor, *PE* physical education, *SB* sedentary behaviours, *SCT* Social Cognitive Theory, *SDT* Self Determination Theory, *SR* self-reported, *SS* sample size, *ST* - Sedentary Time, *ScT* – Screen Time, *SB-BI* Short-Term Behavioral Intention, VPA - vigorous intensity physical activity, *7-PAR* 7-Day Physical Activity Recall.

publication year; * mean (standard deviation). Outcomes: = , ↑ and ↓ indicate no statistically significant differences, and statistically significant ($p < 0.05$) increases and decreases, respectively; "vs" indicates between-group interactions. Holistic Category: Single-domain; Multi-domain with low, moderate, or high integration.

Grasten et al., 2017) measured self-reported habitual PA and SB using a combination of validated questionnaires and study-specific self-report instruments.

3.3. School setting

Nine RCTs (Ahmed et al., 2022; Bronikowski et al., 2016; Bronikowski et al., 2018; da Silva Bandeira et al., 2020; Dewar et al., 2014; Hankonen et al., 2017; Sanaeinasab et al., 2012; Schnider et al., 2022; Whittemore et al., 2013) and one CT (Grasten et al., 2017) published from 2012 to 2022 were included. The number of participants in these studies ranged from 43 to 1085 and the intervention duration ranged from six weeks to one calendar year. All the studies included at least one or two post-intervention follow-up measures. All studies used one or more theories to design interventions focused on increasing adolescents' PA, reducing SB, and enhancing psychosocial variables. Some interventions were implemented during the school schedule, either during physical education or sport-related school programs (Bronikowski et al., 2016; Bronikowski et al., 2018; da Silva Bandeira et al., 2020; Schnider et al., 2022), while others involved a combination of school-based educational sessions and extracurricular activities, such as lunch-time or break activities (Ahmed et al., 2022; Dewar et al., 2014; Grasten et al., 2017; Hankonen et al., 2017; Sanaeinasab et al., 2012). One study was specifically focused on a school-based intervention not limited to the PE classes (Whittemore et al., 2013) (Table 1).

3.3.1. Determinants – school setting

In total, 28 unique determinants were analysed after merging closely related ones into broader categories (18 individual–psychological, 4 individual–behavioural, and 6 interpersonal). Four determinants, each examined in more than two studies, were included in the meta-analysis (Table 2; Fig. 2a–c). Results showed moderate evidence for the absence of an effect for family support ($d = -0.065$, 95% CI −0.433–0.229), school support ($d = -0.105$, 95% CI −0.712–0.431), and self-efficacy ($d = -0.029$, 95% CI −0.253–0.288), all with small or negligible effect sizes. For planning (considered as a self-regulatory determinant of PA behaviour), weak evidence suggesting a possible positive effect was found ($d = 0.466$, 95% CI -0.731-1.265), although the 95% CI crosses the estimate threshold. Heterogeneity ranged from small to moderate, with planning being the highest (Table 2). Publication bias was evaluated using Bayes factors, and the resulting evidence for small-study effects is reported in Table 2. The remaining 22 determinants were summarized narratively.

Table 2
Results of Robust-Bayesian-Meta-Analyses (RoBMAs) in the school setting for PA, SB, and determinants and the associated heterogeneity and publication bias assessments.

	Effect size estimates (95%CI)	BF_{10}
MA – Family support (Fig. 2a)	−0.065 (−0.433, 0.229)	0.125*
Heterogeneity (τ)	0.122 (0.031, 0.414)	-
Publication bias	-	0.533
MA – Planning (Fig. 2b)	0.466 (−0.731, 1.265)	1.179#
Heterogeneity (τ)	0.706 (0.196, 1.831)	-
Publication bias	-	2.260
MA – School support (Fig. 2c)	−0.105 (-0.712, 0.431)	0.240*
Heterogeneity (τ)	0.423 (0.174, 0.991)	-
Publication bias	-	0.636
MA – Self-efficacy (Fig. 2d)	−0.029 (−0.253, 0.288)	0.118*
Heterogeneity (τ)	0.151(0.037, 0.396)	-
Publication bias	-	0.986
MA – PA (Fig. 2e)	0.405 (−0.359, 1.083)	0.803*
Heterogeneity (τ)	1.009 (0.615, 1.696)	-
Publication bias	-	0.629
MA – SB (Fig. 2f)	−0.200 (−0.599, 0.216)	0.409*
Heterogeneity (τ)	0.335 (0.131, 0.766)	-
Publication bias	-	0.443

Note: #anecdotal evidence for presence of an effect, *anecdotal evidence for absence of an effect.

3.3.2. Physical Activity and sedentary behaviours – school setting

One RoBMA was conducted for PA (Fig. 2e) and one for SB (Fig. 2f). Both PA ($d = 0.405$, 95% CI -0.359, 1.083) and SB ($d = -0.200$, 95% CI -0.599, 0.216) results provide anecdotal evidence favouring the absence of an effect, with heterogeneity and uncertainty ranging from moderate to large. Moderate evidence for the absence of publication bias was found for both PA and SB (Table 2).

3.3.3. Controlled trial – school setting

No meta-analysis was performed for the controlled trial evidence in the school setting because only one controlled trial was available (Grasten et al., 2017).

3.3.4. Risk of bias assessment – school setting

3.3.4.1. Randomized Controlled Trials. The results of the risk of bias assessment are presented in the traffic light plot in Fig. 3a. An overall high risk was assessed for seven of the studies in the school setting (Aittasalo et al., 2019; Bronikowski, et al., 2016, 2018; Cowley et al., 2021; Hankonen et al., 2017; Moreno et al., 2021; Sanaeinasab et al., 2012). Domain 4 (risk of bias in the measurement of the outcome) accounted for most of the observed concerns. In many studies, awareness of group allocation could have affected participants' responses, thereby increasing the risk of biased outcome measurement.

Domain 1 (randomization process; 20% high risk), Domain 2 (deviations from intended interventions; 10% high risk), and Domain 3 (missing outcome data; 10% unclear risk) contributed to overall bias to a lesser extent. In Domain 1, the risk was mainly due to inadequate or insufficiently reported randomization, whereas in Domain 2 it stemmed from the absence of analyses accounting for the effect of assignment to intervention.

3.3.4.2. Controlled Trials. Overall high risk of bias was identified for the single CT conducted in the school setting (Grasten et al., 2017) primarily due to concerns in Domain 1-confounding, Domain 6-outcome measurement of PA/SB, and Domain 7-measurement of determinants (Fig. 3b).

3.3.5. Certainty of the evidence

Certainty of evidence was rated as moderate for family support, low for PA, SB, and school support, and very low for planning and self-efficacy. All outcomes were downgraded for serious risk of bias. Additional downgrading was applied for inconsistency (PA, planning, school support, self-efficacy) and for imprecision (planning, SB, self-efficacy). SB and PA were considered critical behavioural outcomes, whereas all modifiable determinants, including family support, planning, school support, and self-efficacy were considered important mechanistic outcomes (Table 3).

3.4. School and home setting

One RCT (Aittasalo et al., 2019) and one CT (González-Cutre et al., 2018), both theory-based and published between 2018 and 2019, were included. Delivered in the school setting, these interventions aimed to promote habitual PA – reported by means of ad hoc questionnaires and surveys – through structured programs and motivational strategies. Sample sizes ranged from 88 to 1,550, with intervention durations of four to six weeks. Both studies included post-intervention follow-up assessments and primarily targeted increases in adolescents' PA, reductions in SB, and improvements in related psychosocial variables (Table 1).

Aittasalo's RCT (Aittasalo et al., 2019) implemented a brief, multimodal intervention for Finnish adolescents in health class using GIS

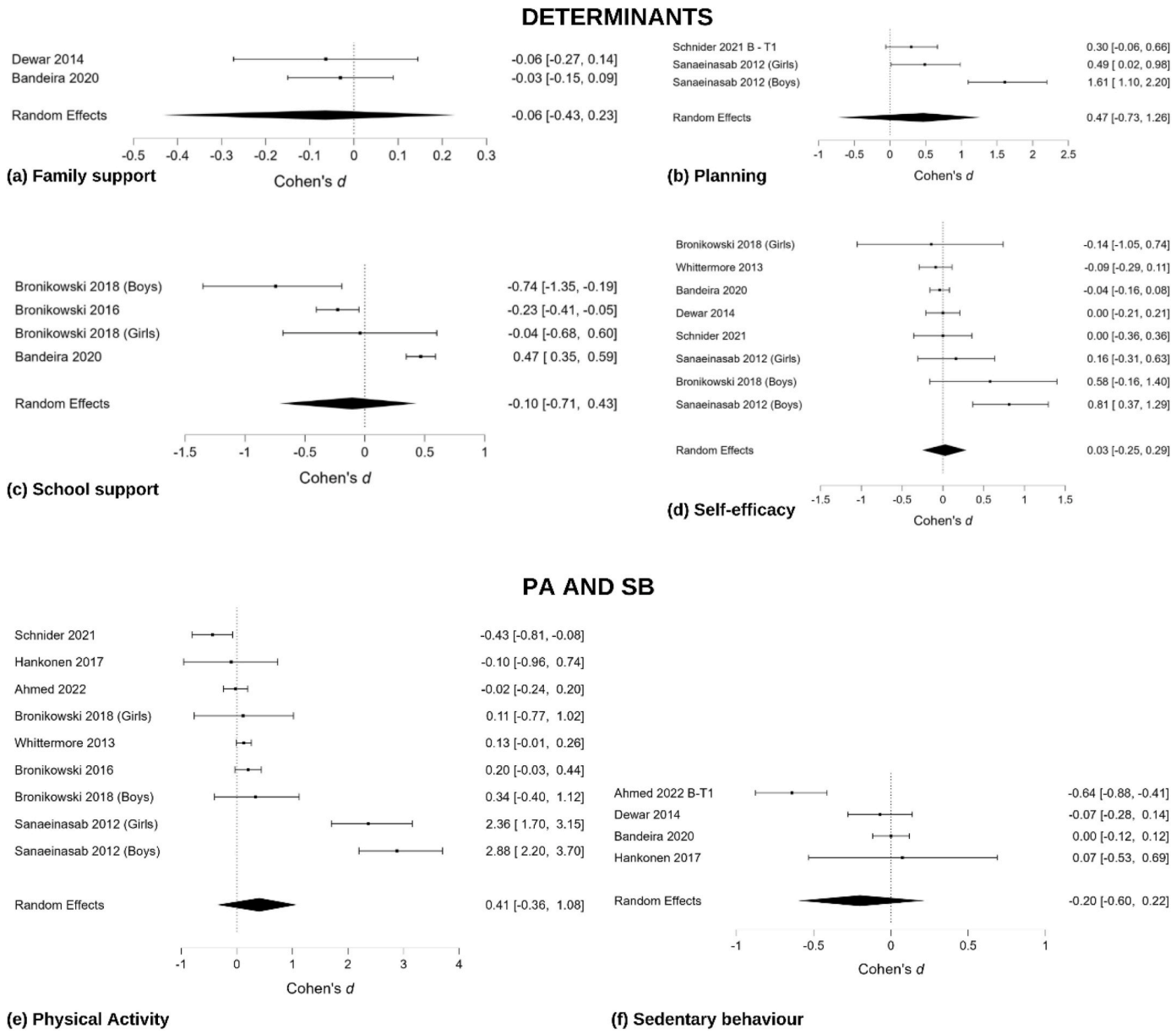


Fig. 2. Forest plots of effects of interventions on determinants, PA and SB in the school setting.

mapping, videos, and interactive tasks, including homework for orientation, intention building, and action planning. In contrast, González-Cutre's CT (González-Cutre et al., 2018) engaged Spanish adolescents through a multidimensional, PE-based program that included extracurricular activities and family meetings to foster motivation and improve physical activity habits.

3.4.1. Determinants – school and home setting

Across the two trials, 18 unique determinants were identified, including five individual-psychological and 13 interpersonal constructs. In the trial by Aittasalo and colleagues (Aittasalo et al., 2019), intention for leisure PA showed only a minimal standardized effect ($d \approx 0.14$, 95% CI 0.02 to 0.26), with no consistent post-intervention advantage over the comparison group in other individual-psychological constructs. Likewise, interpersonal constructs showed minimal change: family norms for walking or cycling to school and for leisure PA yielded minimal effects ($d \approx 0.14$, 95% CI 0.02 to 0.26; $d \approx -0.02$, 95% CI −0.14 to 0.09), and only the family norms about limiting screen time reached the small-effect range ($d \approx 0.31$, 95% CI 0.19 to 0.43). None of these effects translated into substantive improvements in self-reported PA.

In contrast, the trial by González-Cutre and colleagues (González-Cutre et al., 2018) examined a broader set of motivational constructs and reported consistently small to moderate effects across several indicators. Autonomy support from teachers, peers and parents typically ranged from small to medium magnitude (Cliff's d values ≈ 0.18 to 0.46), while satisfaction of competence, autonomy and relatedness showed similar small effects. Autonomous forms of motivation, particularly intrinsic, identified and integrated regulation across PE and leisure-time contexts, demonstrated small to moderate improvements (d values ≈ 0.20 to 0.53). Controlled motivation and amotivation, by contrast, showed negligible or small effects (most $d < 0.20$). Despite these motivational gains, no corresponding sustained changes in PA behaviour were observed. When considered together, the findings from both studies indicate limited responsiveness of individual-psychological and interpersonal determinants to intervention strategies, and none displayed a consistent association with PA behaviour across studies.

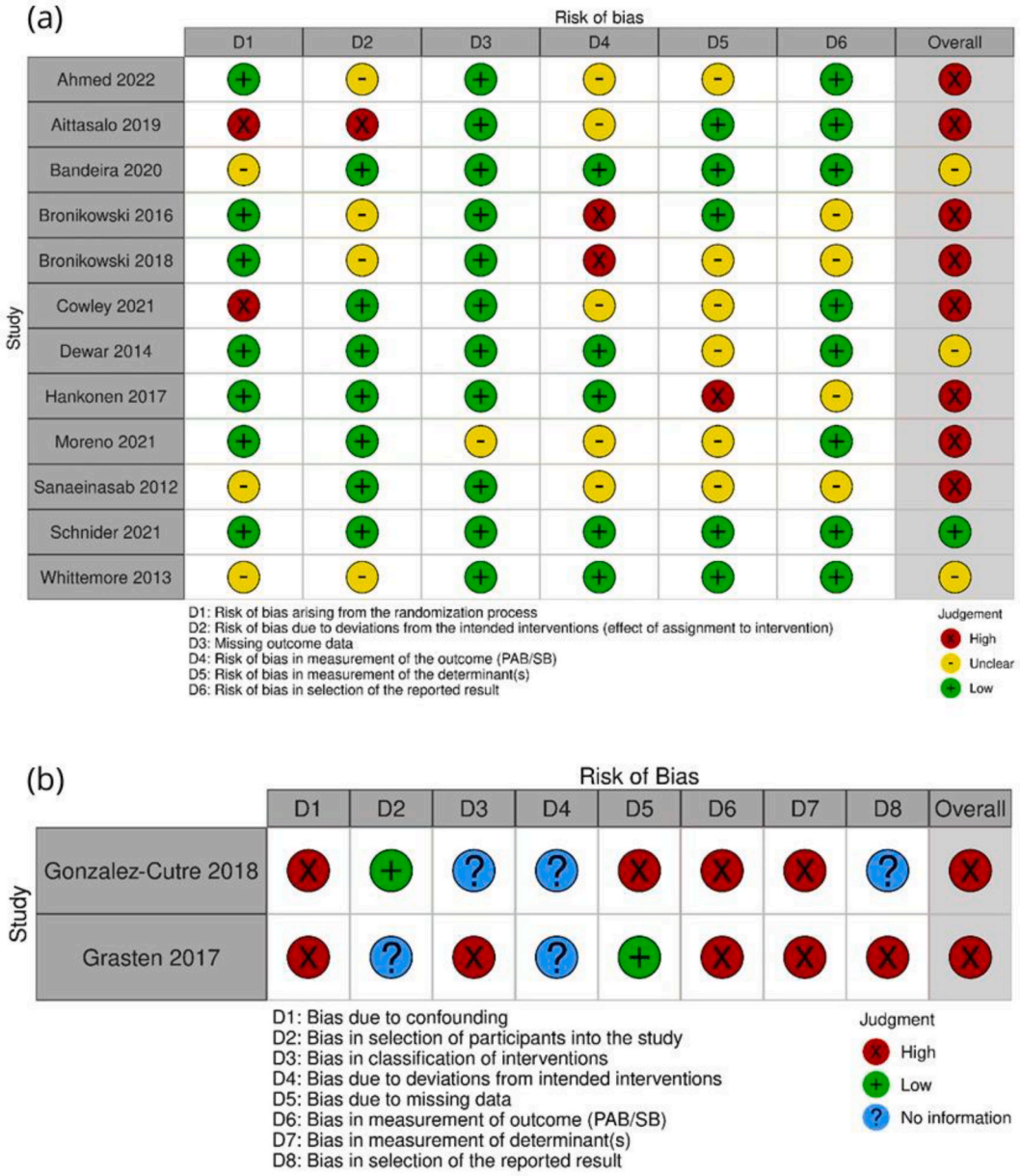


Fig. 3. Risk of bias assessments of (a) Randomized Controlled Trials and (b) Controlled Trials.

3.4.2. *Physical Activity – school and home setting*

Across the two interventions, self-reported behavioural outcomes showed small favourable changes. In Aittasalo et al. (2019), the intervention produced a small increase in weekly days with at least 1 h of brisk leisure PA (Δ = 0.3 days, 95% CI 0.1 to 0.6) and a higher proportion of adolescents meeting PA guidelines (Δ = 4.1%, 95% CI 2.5 to 5.7). These changes correspond to small effect sizes (d ≈ 0.15–0.25). No meaningful differences were observed for sedentary behaviour (Δ = −0.1 days, 95% CI −0.3 to 0.1). In González-Cutre et al. (2019), a modest improvement in self-reported PA was also detected, with students in the intervention arm reporting a higher frequency of weekly PA participation (d = 0.20, 95% CI −0.05 to 0.45), although this estimate did not reach statistical significance. Taken together, the evidence from both studies indicates consistently small but positive changes in self-reported PA and negligible effects on SB.

3.4.3. *Risk of bias assessment – school and home setting*

3.4.3.1. Randomized controlled trial. The RCT (Aittasalo et al., 2019) was judged to have an overall high risk of bias. This judgment was primarily driven by high-risk ratings in several domains. In D1 (randomization process), concerns arose due to limited reporting on allocation concealment and baseline imbalances suggesting potential problems in the random sequence implementation. In D2 (deviations from intended interventions), substantial deviations from the protocol occurred without clear evidence that these were unrelated to group allocation. In D5 (measurement of determinants), the use of self-reported measures with insufficient information on their validity and potential differential measurement across groups contributed to a high risk of bias. These issues collectively justified the overall high-risk assessment (Fig. 3a).

3.4.3.2. Controlled trial. The CT (González-Cutre et al., 2018) was also judged at a high overall risk of bias, due to significant concerns across

Table 3
Quality of evidence (Grading Recommendations to Assess Development and Evaluation system, GRADE) of Physical Activity, Sedentary Behaviour, and modifiable determinants in school setting.

Outcome	Studies	(1)	(2)	(3)	(4)	(5)	Effect (95%CI)	Certainty
PA	Ahmed 2022; Bronikowski 2016; Bronikowski 2018 (Boys); Bronikowski 2018 (Girls); Hankonen 2017; Sanaeinasab 2012 (Boys); Sanaeinasab 2012 (Girls); Schnider 2021; Whittermore 2013	serious[a]	serious[b]	not serious	not serious	none	0.05 (0.22 to 0.13)	⨁⨁◯◯ Low
SB	Ahmed 2022; Bandeira 2020; Dewar 2014; Hankonen 2017	serious[a]	not serious	not serious	serious[c]	none	0.13 (0.23 to 0.03)	⨁⨁◯◯ Low
Family support	Bandeira 2020, Dewar 2014	serious[a]	not serious	not serious	not serious	none	0.05 (0.17 to 0.06)	⨁⨁⨁◯ Moderate
Planning	Sanaeinasab 2012 (Boys); Sanaeinasab 2012 (Girls); Schnider 2021	serious[a]	serious[b]	not serious	serious[c]	none	0.49 (0.63 to 0.91)	⨁◯◯◯ Very low
School support	Bandeira 2020; Bronikowski 2016; Bronikowski 2018 (Boys); Bronikowski 2018 (Girls)	serious[a]	serious[b]	not serious	not serious	none	0.2 (0.1 to 0.3)	⨁⨁◯◯ Low
Self-efficacy	Bandeira 2020; Bronikowski 2018 (Boys); Bronikowski 2018 (Girls); Dewar 2014; Sanaeinasab 2012 (Boys); Sanaeinasab 2012 (Girls); Schnider 2021; Whittermore 2013	serious[a]	serious[b]	not serious	serious[c]	none	0.05 (0.23 to 0.07)	⨁◯◯◯ Very low

Given that risk of bias in the measurement of determinants (RoB 2.0 - domain 5) is largely inherent to the nature of the included interventions, this domain was appraised with greater leniency in the GRADE assessment. *CI* Confidence Interval, *PA* Physical Activity, *SB* Sedentary Behaviour.
(1) = Risk of bias, (2) = Inconsistency, (3) = Indirectness, (4) = Imprecision, (5) = Other considerations.
a Downgraded one level due to high and/or some concerns of bias in more than one domain for most included studies in the respective outcome (see Fig. 3).
b Downgraded one level due to inconsistency (due to some variation in effect sizes and confidence intervals; see Fig. 2).
c Downgraded one level due to imprecision (likely due to a smaller sample size or high variability within the study population; see Fig. 2).

multiple domains, including D1-confoundings, D4-deviations from intended interventions, D5-missing data, D6-bias in the measurement of outcomes and D7-determinants (Fig. 3b).

3.5. Home setting

Two RCTs conducted in the home setting were included in the review (Cowley et al., 2021; Moreno et al., 2021). A summary of study characteristics is provided in Table 1. Across these studies, six unique determinants of PA were identified and analysed, categorized as five individual-psychological and one interpersonal.

3.5.1. Intervention outcomes – home setting

In Cowley et al. (2021), small but statistically significant improvements were observed for intrinsic motivation ($d = 0.35$, 95% CI 0.03 to 0.67) and body appreciation ($d = 0.56$, 95% CI 0.23 to 0.89), with a marginal positive effect for perceived competence ($d = 0.28$, 95% CI −0.04 to 0.60). No meaningful changes emerged for amotivation ($d = 0.12$, 95% CI −0.20 to 0.44), external regulation ($d = 0.18$, 95% CI −0.15 to 0.51), introjected regulation ($d = 0.09$, 95% CI −0.24 to 0.41), or identified regulation ($d = -0.03$, 95% CI −0.35 to 0.30). Self-reported habitual physical activity showed no difference between groups ($d = -0.03$, 95% CI −0.35 to 0.29), and sedentary outcomes showed similarly negligible effects ($d \approx 0.00$). Although the home-based intervention did not change physical activity behaviour, it elicited favourable changes in the psychological determinants of intrinsic motivation and body appreciation. Adherence was high, with participants completing an average of 18 ± 2 sessions over the six-week programme.

In Moreno et al. (2021), a small reduction was observed in adolescents' perceived importance of digital technology use, with the intervention group showing a modest decline in ADTI total scores relative to controls ($d = -0.22$, 95% CI −0.42 to −0.02). No meaningful changes were found for adolescent-reported physical activity ($d = 0.05$, 95% CI −0.15 to 0.25), and the single interpersonal determinant, media-rule engagement, remained unchanged ($d = -0.01$, 95% CI −0.11 to 0.09). Overall, the intervention produced a small shift in technology-related attitudes but did not influence PA behaviour or interpersonal rule-engagement processes.

3.5.2. Risk of bias assessment – home setting

The study by Cowley et al. (2021) was judged to have a high overall risk of bias, primarily due to concerns regarding Domain 1-randomization process. The study by Moreno et al. (2021) was rated at a low overall risk of bias (Fig. 3a).

3.6. Sensitivity analysis

For outcomes requiring estimations of composite scores, the sensitivity analysis showed no difference in the calculated effect sizes when the assumed correlation coefficient (r) was set at 0.2, 0.5, or 0.8, indicating the findings were robust.

3.7. Holistic classification of determinant domains

Across the 56 study-domain classifications (14 studies × four determinant domains), reviewers agreed on 50 classifications before consensus, corresponding to an overall descriptive agreement of 89.3%. Domain-specific agreement was 92.9% for individual-psychological determinants ($\kappa = 0.81$), 92.9% for individual-behavioural determinants ($\kappa = 0.81$), and 92.9% for interpersonal determinants ($\kappa = 0.86$), indicating almost perfect agreement. Agreement was lower for environmental determinants (78.6%; $\kappa = 0.51$), indicating moderate agreement and reflecting the greater interpretative complexity of distinguishing environmental components included in intervention design from environmental determinants measured as pre-post outcomes. Across the fourteen studies analysed, the holistic determinant classification showed substantial variability in the breadth and degree of integration of targeted determinants (Supplementary file 5). Four studies (29%) demonstrated high-integration multi-domain designs, explicitly coordinating psychological, behavioural, interpersonal and environmental mechanisms within coherent theoretical frameworks (Cowley et al., 2021; González-Cutre et al., 2018; Hankonen et al., 2017; Sanaeinasab et al., 2012). Six studies (43%) showed moderate levels of integration, typically combining behavioural and psychological strategies with supportive, but less systematically coordinated, interpersonal or environmental elements (Aittasalo et al., 2019; da Silva Bandeira et al., 2020; Dewar et al., 2014; Grasten et al., 2017; Schnider et al., 2022; Whittemore et al., 2013). Three interventions (21%) displayed low-integration multi-domain approaches, relying on isolated behavioural strategies or narrow psychological constructs with minimal linkage across domains (Ahmed et al., 2022; Bronikowski, et al., 2016, 2018). Only one study (7%) reflected a single-domain approach, focusing exclusively on interpersonal media-governance mechanisms

(Moreno et al., 2021). Overall, these findings indicate that, while most interventions addressed multiple determinant domains, only a minority operationalised genuinely interdependent pathways across psychological, behavioural, interpersonal and environmental levels.

As shown in Table 4, environmental or organisational components were embedded in several intervention designs, for example through school-space modifications, curricular integration, digital resources, home-based rules, or structured opportunities for activity. However, these components were not operationalised as measured environmental determinants at pre- and post-intervention. Consequently, they contributed to the holistic intervention profile but could not be included in the quantitative synthesis of measured modifiable determinants.

4. Discussion

This review synthesised evidence from RCTs and CTs to examine how modifiable determinants relate to adolescents' PA and SB across different settings. The findings highlight the diversity of determinants investigated and the predominantly poor intervention effects, with little evidence of consistent effectiveness.

4.1. Key findings

Sixty-seven modifiable determinants were identified across eligible studies: 39 individual-psychological, four individual-behavioural, and 24 interpersonal. Several determinants appeared consistently across settings, including self-efficacy, intention, school and family support, autonomous and controlled motivation, and planning.

Meta-analyses of four school-based determinants provided anecdotal evidence for the absence of effects of school support, family support and self-efficacy on PA or SB, despite their prominence in previous interventions and umbrella reviews that reported positive associations with PA/SB (Cortis et al., 2017; Jaeschke et al., 2017; Kracht et al., 2024; Russell et al., 2025; Singh et al., 2024; Stierlin et al., 2015). Planning showed weak Bayesian evidence suggesting a possible effect; however, the estimate was imprecise, the credible interval was wide, and the certainty of evidence was low. This finding should therefore be interpreted cautiously as it reflects the contrasting findings of the two contributing studies: in (Sanaeinasab et al., 2012), planning - conceptualised as commitment to a plan of action - was a significant independent predictor of weekly PA, whereas (Schnider et al., 2022), using validated action and coping planning scales, found no corresponding changes in PA or evidence of mediation. Overall, planning may hold theoretical relevance for supporting PA behaviour, but heterogeneous operationalisations and inconsistent results limit the strength of current conclusions.

Narrative findings provided further insight into the variability of determinant–behaviour patterns. Some studies reported changes in determinants accompanied by corresponding changes in PA/SB, suggesting a potential alignment between hypothesised mechanisms and behavioural outcomes. Others reported changes in determinants without changes in PA/SB or vice versa, indicating potential mismatches between targeted mechanisms and observed behavioural responses. For instance, although Cowley et al. (2021) reported improvements in intrinsic motivation and body appreciation, these changes did not translate into higher PA levels. From a Self-Determination Theory (SDT) perspective (Ryan & Deci, 2020), increases in intrinsic motivation alone may be insufficient to produce behavioural change when not accompanied by supportive environmental conditions or opportunities for action. This pattern aligns with evidence showing that shifts in motivational quality often predict PA only when embedded within broader social and contextual supports (Teixeira et al., 2020). Similarly, enhanced body appreciation may reflect a psychosocially relevant determinant change, but its implications for mental health or well-being cannot be inferred unless such outcomes are directly assessed. These cases highlight that changes in individual-level determinants, particularly when interventions primarily focused on psychological constructs without concurrently addressing behavioural, interpersonal, or environmental mechanisms, may be insufficient to elicit meaningful behavioural change. Moreover, in some instances PA/SB outcomes changed in the absence of measurable determinant shifts, raising questions about the adequacy, timing, or sensitivity of determinant measurement. Such heterogeneity underscores the importance of reporting narrative patterns in addition to pooled effects.

The comparison with a recent DE-PASS review of device-based PA/SB determinants (Kolovelonis et al., 2024) reveals notable parallels. That review also identified numerous determinants but found negligible pooled effects on both determinants and device-based PA/SB, together with narrative evidence of determinant changes that did not translate into behaviour change. These similarities suggest that the weak or inconsistent intervention effects observed in the present review are not specific to self-reported outcomes but may reflect broader challenges in modifying determinants at scale, insufficient intervention fidelity or duration, or limited potency of determinant focused strategies.

Finally, the predominantly low/very low-GRADE certainty for school setting meta-analyses indicates that minimal or ineffective modification of targeted determinants likely contributed to the non-significant PA and SB outcomes, consistent with previous recommendations on the importance of effective determinant targeting (Sallis, Bull, et al., 2016).

4.2. Interpretation of holistic findings

The holistic classification conducted in this review highlights substantial variability in the extent to which interventions simultaneously targeted psychological, behavioural, interpersonal and environmental determinants of adolescent PA and SB (Supplementary file 5). Within the studies, all environmental determinants (e.g., school and home environment modification, mapping tools, physical and digital spaces) were presented narratively as intervention elements but were not measured.

Table 4
Holistic classification matrix: targeted intervention components and measured determinants by study.

Study	Intervention components targeted or embedded in design	Determinants measured pre-post
Ahmed et al. (2022)	I-Psy; I-Beh; Int; Env/Org	I-Psy
Aittasalo et al. (2019)	I-Psy; I-Beh; Int; Env/Org	I-Psy; Int
da Silva Bandeira et al. (2020)	I-Psy; I-Beh; Int; Env/Org	I-Psy; Int
Bronikowski et al. (2016)	I-Beh; Int	Int
Bronikowski et al. (2018)	I-Beh; Int	I-Psy; Int
Cowley et al. (2021)	I-Psy; I-Beh; Int; Env/Org	I-Psy
Dewar et al. (2014)	I-Psy; I-Beh; Int; Env/Org	I-Psy; I-Beh; Int
González-Cutre et al. (2018)	I-Psy; I-Beh; Int; Env/Org	I-Psy; Int
Gråstén et al. (2017)	I-Psy; I-Beh; Int; Env/Org	I-Psy
Hankonen et al. (2017)	I-Psy; I-Beh; Int; Env/Org	I-Beh
Moreno et al. (2021)	Int; Env/Org	Int
Sanaeinasab et al. (2012)	I-Psy; I-Beh; Int; Env/Org	I-Psy; I-Beh; Int
Schnider et al. (2022)	I-Psy; I-Beh; Int; Env/Org	I-Psy; I-Beh
Whittemore et al. (2013)	I-Psy; I-Beh; Int; Env/Org	I-Psy

Note. *I-Psy* = individual-psychological; *I-Beh* = individual-behavioural; *Int* = interpersonal; *Env/Org* = environmental or organisational. "Intervention components targeted or embedded in design" refers to domains addressed by the intervention logic, delivery structure, materials, social support, setting modifications, digital tools, or organisational arrangements. "Determinants measured pre-post" refers only to constructs assessed as modifiable determinants at pre- and post-intervention. Environmental or organisational components could be present in intervention designs but absent from the quantitative synthesis of measured environmental determinants.

Only a minority of trials demonstrated high levels of integration, in line with contemporary socioecological and motivational frameworks emphasising the interdependence of these domains (Bauman et al., 2012; Sallis et al., 2015). Combining need-supportive psychological strategies with structured behavioural practice, supportive social environments and contextual scaffolding seems to enhance the likelihood of sustained behaviour change (Cowley et al., 2021; González-Cutre et al., 2018; Hankonen et al., 2017; Sanaeinasab et al., 2012). This pattern aligns with findings from high-quality implementation studies demonstrating that multi-component, theory-grounded interventions tend to produce more consistent improvements in youth PA and related psychosocial outcomes (Biddle et al., 2019; Lubans et al., 2016). By contrast, many included programmes relied on low-integration approaches characterised by isolated behavioural techniques or by a limited focus on one or two individual-level psychological constructs (e.g., self-efficacy or intention), without coordinated engagement of complementary psychological processes or other domains. This issue is particularly relevant for school-based interventions. Although school was used as a setting category in this review, schools should not be viewed merely as delivery locations. They are complex systems in which adolescents' PA and SB are shaped by peers, teachers, timetables, curricula, institutional norms, policies, facilities, and physical spaces. Accordingly, school-based PA/SB interventions may require system-level alignment rather than isolated psychological, behavioural, or interpersonal strategies, especially because most measured determinants in this review were individual-psychological or interpersonal, whereas environmental and organisational determinants were rarely operationalised as pre-post outcomes (Langford et al., 2014; Morton et al., 2016). A similar contextual interpretation is needed for home-based and digitally supported interventions. These approaches may increase reach, flexibility, autonomy, and tailoring, but they also raise challenges related to adherence monitoring, fidelity, engagement, supervision, and equity of access. Their variable effects may therefore depend not only on intervention content or traditional FITT parameters, but also on density, timing, context, and how PA/SB opportunities are distributed within adolescents' daily routines. Future studies should report adherence, dose, engagement, fidelity, and adaptations to clarify whether the intended components were received and enacted as planned (Herold, et al., 2024, 2025). Similar limitations have been noted in previous reviews (Pesce et al., 2021; van Sluijs et al., 2021), which report that single-domain strategies rarely yield durable effects given the multifactorial nature of PA behaviour. The predominance of moderate- or low-integration designs in the present evidence base underscores the continued gap between theoretical models advocating holistic perspectives and the practical delivery of interventions. Rather than demonstrating the superiority of multicomponent approaches, these findings generate a testable hypothesis: future trials should examine whether interventions that intentionally integrate psychological, behavioural, interpersonal, organisational, and environmental mechanisms produce more consistent changes in adolescents' PA and SB than interventions focused mainly on individual-level determinants.

4.3. Theoretical and methodological implications

Most interventions employed theoretical frameworks (e.g., Social Cognitive Theory, SDT, Ecological Models). Nevertheless, significant effects on determinants or PA/SB remained elusive across settings, despite utilisation of psychometrically sound measures. One possible explanation for these weak or inconsistent effects is that several interventions may have relied predominantly on cognitive or self-regulatory strategies, such as knowledge provision, goal-setting, planning, monitoring, or social support, without sufficiently targeting adolescents' affective and motivational experience of PA. Behaviour change may be difficult to sustain when PA is not experienced as enjoyable, autonomy-supportive, socially rewarding, competence-enhancing, or personally meaningful. From this perspective, the limited translation of determinant change into PA/SB change may partly reflect insufficient attention to affective responses, identity, autonomy, perceived competence, and the quality of social experiences. Future interventions should therefore move beyond the inclusion of theory-based components per se and specify how these components are expected to shape adolescents' affective and motivational engagement over time (Ekkekakis & Brand, 2021; Klos et al., 2020). This observation aligns with critiques highlighting weak associations between, for example, core SDT tenets (e.g., autonomous motivation) and youth PA/SB (Robbins et al., 2019), suggesting potential deficiencies in theory application or study design (Gourlan et al., 2023). Two overarching issues warrant emphasis: 1) The predominance of individual- and interpersonal-level determinants in the present evidence base reflects, at least in part, the eligibility criteria adopted in this review, which required determinants to be operationalised and measured at the individual or interpersonal level. Consequently, interventions primarily targeting psychological or social processes were more likely to be included, whereas interventions acting mainly on structural, environmental, or policy-level mechanisms were less likely to meet inclusion criteria. This focus may accentuate theories emphasising personal agency and self-regulation (Hagger & Weed, 2019), which, when considered in isolation, may overestimate individual capacity for behaviour change and underrepresent the influence of contextual and structural constraints (Chastin et al., 2016; Condello et al., 2016; Koh et al., 2024; Ling et al., 2024). 2) Implicit processes have been overlooked - Interventions rarely addressed automatic motivation (e.g., habit, impulse), despite its centrality within the Capability-Opportunity-Motivation-Behaviour (COM-B) model for disengaging from ingrained sedentary routines (Cheval et al., 2021; Michie et al., 2011). Neglect of implicit processes may substantially limit intervention efficacy (Yeager et al., 2018).

4.4. Limitations and methodological considerations

4.4.1. Review-level limitations

The limitations of this review should be distinguished from limitations of the included studies. First, the final search update was completed in July 2023. A further formal update was not conducted during revision because it would have required repetition of the full systematic review process, including screening, extraction, risk-of-bias assessment, certainty assessment, holistic coding, and quantitative synthesis by independent reviewers. Therefore, the findings should be interpreted as a synthesis of eligible studies published within the registered search window. This is an important review-level limitation because the field has continued to develop, particularly in relation to 24-h movement behaviour frameworks, digital and home-based delivery, sex and gender differences, weekday versus weekend contexts, sedentary behaviour subtypes, and biological or developmental moderators.

Second, the review focused specifically on self-reported PA and SB. Self-report instruments are practical, scalable and able to capture perceived barriers, behavioural domains, motivations, activity types, and contextual information that device-based measures cannot easily provide. This is particularly relevant for determinant-based intervention research, where understanding perceived context and psychosocial mechanisms is central to interpreting behaviour change and useful for surveillance, programme evaluation and policy planning (Nelson et al., 2019; Sattler et al., 2021). However, the conclusions of this review apply specifically to self-reported PA and SB and should not be assumed to generalise directly to device-measured movement behaviours.

Third, eligibility criteria required determinants to be measured at least at pre– and post-intervention to be included in the quantitative synthesis. As a result, policy-level and most environmental determinants were not represented as outcomes in the included RCTs/CTs. This does not imply that such determinants are irrelevant or untargeted in intervention research, but because they typically fall outside the scope of what was operationalised and measured as directly modifiable within the trials. The relatively limited number of studies available for certain

MAs constrained meaningful interpretation of the findings, contributed to imprecision in the GRADE and heterogeneity assessments. This made direct comparison of intervention approaches challenging which has been noted in other similar reviews (Dobbins et al., 2013; Kolovelonis et al., 2024; Ling et al., 2024).

Finally, adolescents aged 13 to 19 years were treated as a single group. This was consistent with the review eligibility criteria, but adolescence includes substantial biological, cognitive, emotional, and social changes. Intervention effects may vary according to pubertal status, biological maturity, sex/gender, school transitions, autonomy, and changing family or peer influences. However, the included studies did not provide sufficient information to conduct subgroup analyses by maturation or developmental stage. Recent work on maturation assessment in youth sport highlights the feasibility and relevance of considering biological maturity when interpreting adolescent sport and exercise data (Shang et al., 2025). Therefore, the present findings should be interpreted as applying to adolescents broadly rather than to specific maturational subgroups.

4.4.2. Limitations of the included studies

Several limitations concerned the primary studies. Self-reported PA and SB were affected by measurement limitations, including recall and social desirability biases, inconsistent item wording, variable recall periods, and differences in whether instruments capture total behaviour, specific domains, or contextual features. In addition, not all included studies used fully validated self-report instruments; some relied on study-specific or non-standard items, translated measures without full validation in the target language, or instruments for which validation was not explicitly reported. These issues may contribute to overestimation of PA, underestimation of SB, and difficulty comparing outcomes across studies (Sattler et al., 2021). They are especially relevant in adolescence, because movement behaviours vary by setting, day type, social context, and activity purpose, which may not be captured consistently across self-report tools. Future trials should, where feasible, combine validated self-report tools with device-based measures and ensure that self-report instruments are sufficiently sensitive to setting, day type, activity context, and sedentary behaviour subtype.

Another measurement-related consideration concerns the distinction between SB quantity and SB quality. In the included trials, SB was generally treated as a total behavioural outcome, which was consistent with the available data but may obscure meaningful differences between SB types. Passive screen viewing, gaming, internet use, reading, homework, and cognitively engaging sedentary activities should not be interpreted as equivalent exposures, because they may differ in their developmental, cognitive, affective, and social implications. Recent work has suggested that SB should be differentiated according to cognitive, neurobiological, and contextual characteristics rather than treated as a single uniform exposure (Zhang et al., 2025; Zou et al., 2024). Evidence from simulated classroom research further suggests that interrupting prolonged sitting with exercise breaks may have cognitive and neurophysiological relevance, supporting the need to consider how PA/SB opportunities are timed and distributed across daily routines (Yu et al., 2025). Longitudinal evidence also indicates that specific SB types may show sex-dependent associations with later academic outcomes, with internalizing and externalizing problems acting as potential mediating pathways (Guan et al., 2026). Therefore, the present findings on SB should be interpreted as referring mainly to the total or broadly defined sedentary outcomes available in the included trials.

Interpretation was further complicated by incomplete intervention reporting. Determinant-based PA/SB interventions require sufficient detail on intervention content, dose, delivery mode, provider expertise, supervision, adaptations, adherence, fidelity, and behaviour change techniques to determine whether the intended mechanisms were actually delivered and whether the targeted determinants were likely to change. Recent evidence on non-pharmacological intervention trials indicates that even randomized controlled trials may omit key details, including modifications, motivational strategies, and qualified supervision, thereby limiting replication and interpretation (van Ierssel et al., 2024). Future trials should therefore use established reporting frameworks, such as the Template for Intervention Description and Replication (TIDieR), specify behaviour change techniques using recognised taxonomies, report intervention dose and adaptations, and assess whether the targeted determinants changed as intended.

Risk of bias assessment identified substantial concerns across the included studies, primarily attributable to lack of participant blinding, and outcome measurement bias, both critical for behavioural outcomes. However, blinding participants in PA/SB interventions remains a persistent methodological challenge (Boutron et al., 2007). RoBMA was employed to quantify evidentiary strength continuously while adjusting for publication bias, evaluating support for null, alternative, or inconclusive hypotheses. Crucially, causal inference was constrained by the absence of mediation analyses testing determinant-behaviour pathways in all included studies (Biddle et al., 2019).

4.5. Future directions: advancing theory, methods, and scale

To address these limitations and advance the field, future research should prioritise the following: 1) Elucidating Causal Pathways - Mediation analyses testing mechanisms linking determinants to PA/SB should be prioritized. Despite persistent methodological appeals, implementation remains rare, potentially due to intervention complexity (e.g., multiple determinants). Strategic selection of determinants is essential to mitigate unconscious selection biases and enable robust mediation testing (Ciaccioni et al., 2022; Schuler et al., 2025); 2) Reorienting Intervention Targets - Given the null or inconsistent effects observed for prominent individual/interpersonal-level determinants such as self-efficacy and support, future interventions should further examine environmental and policy determinants, including physical environments, institutional policies, school schedules, transport opportunities, community infrastructure, and access to safe and inclusive spaces for PA. This shift is relevant not only for intervention effectiveness, but also for equity, because adolescents' opportunities to be active may differ by sex/gender, socioeconomic resources, school context, neighborhood conditions, and family constraints (Bergen et al., 2024; Sallis et al., 2006); 3) Expanding Contextual Scope - Investigation should extend beyond home and school settings, including digital environments, transport systems, and built environments. Multi-setting interventions employing transdisciplinary collaboration (e.g., integrating urban planning, education policy, and behavioural science) could help clarify how access, opportunity, and contextual inequities shape determinant-setting interactions and inform scalable policies (Kremers et al., 2006).

Future trials should also directly assess whether changes in PA/SB determinants co-occur with changes in internalizing symptoms, externalizing symptoms, or broader psychosocial outcomes. Although several measured determinants, including motivation, affective responses, perceived competence, body-related perceptions, and social support, are theoretically relevant to adolescent mental health, they should not be interpreted as evidence of mental-health or well-being effects unless such outcomes are directly assessed. Recent evidence suggests that associations between moderate-to-vigorous PA and later internalizing problems may vary by sex/gender and day type, supporting the need to examine psychological outcomes within their developmental and contextual conditions (Zhou et al., 2026). Future PA/SB trials should assess pubertal status, biological maturity, or developmental stage where feasible, and examine whether determinant change and intervention effects differ across adolescent subgroups (Shang et al., 2025).

Future studies would also benefit from methodological developments that address the complexity of PA/SB determinants and the contextual variability across settings. Approaches such as realist synthesis have been proposed to enhance the analysis of policy and environmental interventions by generating explanatory accounts of how

multi-level mechanisms operate within socio ecological systems [e.g. (Cooper et al., 2017; Pesce et al., 2021),]. Similarly, the integration of theories accounting for implicit processes in behaviour change may support the design of more comprehensive intervention frameworks (Michie et al., 2011). These perspectives are aligned with, but not directly implemented within, the present review and therefore represent opportunities for future research rather than methodological contributions of the current study.

Finally, although this review identified a relatively small set of eligible studies, this limitation is primarily attributable to the inclusion criteria and analytic requirements adopted. In reality, numerous intervention studies targeting adolescent PA and SB exist. However, many employ traditional designs or approaches that add limited conceptual or methodological innovation to the field. Consequently, rather than simply calling for a greater number of studies, future research should prioritise the development of methodologically rigorous interventions with more explicit and testable links between theory, intervention components, and measured constructs, in order to elucidate causal mechanisms and advance understanding of modifiable determinants (Biddle et al., 2019).

5. Conclusion

This review found limited and inconsistent evidence for the effectiveness of interventions targeting adolescents' PA, SB, and related modifiable determinants across settings. Weak evidence suggested a possible small positive effect on planning; however, certainty of evidence was generally low to very low, high risk of bias was common, and findings should be interpreted cautiously. The holistic analysis highlighted a mismatch between theoretical models advocating multilevel approaches and the empirical operationalisation and measurement of determinants in intervention trials. However, the present review does not demonstrate that multicomponent interventions outperform single-domain interventions. Rather, it suggests that future trials should test whether interventions intentionally combining psychological, interpersonal, organisational, and environmental components produce more consistent changes in PA/SB than interventions focused mainly on individual-level determinants (Chastin et al., 2016; Ciaccioni et al., 2025; Condello et al., 2016; Stodden et al., 2023; Stodden & Pesce, 2025). Future interventions should adopt: i) greater methodological rigour, including mediation testing, the combined use of validated self-report instruments with device-based measures, and the assessment of domain-specific SB subtypes; ii) contextual breadth, through multi-setting and transdisciplinary approaches; and iii) theoretical sophistication, integrating unconscious drivers and contextual mechanisms. Without such measures, the field risks perpetuating ineffective interventions that fail to engage the structural determinants underpinning health inequities (Koh et al., 2024).

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Not applicable.

Consent for publication

Not applicable.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the author(s) used OpenAI model GPT-5.2 in order to solely assist in double-checking the manuscript for typographical errors, grammatical accuracy, and minor linguistic inconsistencies. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the published article.

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Abbreviations

BCTs: Behaviour Change Techniques; CI: Credible Interval; CT: Controlled Trials; DE-PASS: DEterminants of Physical Activities in SettingS; GIS: Geographic Information System; GRADE: Grading Recommendations to Assess Development and Evaluation system; MA: Meta-Analysis; PA: Physical Activity; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses; RCT: Randomized Control Trial; RoBMA: Robust Bayesian meta-analyses; SB: Sedentary Behaviour; SMD: Standardised mean difference; SR: Systematic Reviews; SRMA: Systematic Reviews and Meta-Analysis; WHO: World Health Organization.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.mhpa.2026.100803.

Data availability

All research data supporting the findings of this study are contained within the manuscript and its associated supplementary files, including figures and tables.

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