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Physical Activity Interventions Using Motion Sensor to Improve Adolescents' Cardiometabolic Health: A Systematic Review and Meta-Analysis

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Abstract

Objective: The purpose this study was systematically review physical activity interventions using motion sensors (with or without access to mHealth technology) on cardiometabolic health in adolescents.Methods: PubMed, Scopus, Cochrane Library, Lilacs, Web of Science, and SPORTDiscus electronic databases were searched on 18October,2019 using predefined terms: population (adolescents, adolescence, youth), intervention (exercise, physical activity), and results (smartphone, mobile applications, pedometer, step counter, motion sensor). Studies included were those which adopted some type of physical activity (structured or unstructured) intervention with motion sensors that provided feedback for self-monitoring with the objective of improving cardiometabolic health in adolescents (12-18 years). To evaluate the risk of bias, Cochrane tool were used. Review Manager 5.3 software was used to perform the meta- analysis. In total, four randomized controlled trials were included in the meta-analysis. Results: A total of 12 articles met the inclusion criteria, 6 of them analyzed in the meta-analysis. The findings of the review indicate that the most commonly used motion sensor in intervention studies was the pedometer. The meta-analysis demonstrated that physical activity interventions using motion sensors for self-monitoring and lasting more than six months promoted a decrease in body mass index, body mass index z-score, and body fat for the intervention group compared to the control group.Conclusion: This systematic review and meta-analysis highlights that the most commonly used motion sensor in intervention studies was the pedometer. Moreover, the results found in this review on the physical activity interventions using motion sensors on cardiometabolic risk factors were summarized as body composition outcomes.

Keywords: step count; overweight; health promotion; youth; motor activity

1. Introduction

Regular physical activity (PA) practice has been associated with numerous health benefits in children and adolescents, including skeletal, physiological, and mental health, as well as improvements in the cardiometabolic profile(Hallal et al., 2006; WHO, 2010). Global recommendations for PA suggest that children and adolescents should perform at least 60 minutes of moderate to vigorous PA every day(WHO, 2010; Committee., 2018), however, global estimates suggest that only 19% of school-aged adolescents (aged 11 to 17 years) meet the current recommendations (Guthold et al., 2020) .

The adolescence period is an essential phase for the establishment and consolidation of life habits, since longitudinal studies have verified that changes in PA level during adolescence tend to be carried over into adulthood (Van Dijk et al., 2016; Harding et al., 2015; Silva et al., 2018; Azevedo et al., 2007). In response to increasing access to technology, research has verified the effects of the use of technologies such as text messages, social networks, sensors, wristbands, and smartphone applications on young people's physical activity (Badawy et al., 2016; Badawy and Barrera, 2017; Gal et al., 2018) .

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Systematic reviews(Lubans et al., 2009) have examined the effects of interventions on the level of habitual PA, in which the pedometer, through self-monitoring, has been a promising tool for increasing PA among adolescents. Currently, advances in mobile health (mHealth) technology have enabled convenient and accurate tracking of physical activity through smartphone applications and wearable devices(Case et al., 2015). Although the literature indicates that the use of motion sensors promotes an increase in PA in this population, there is still a gap regarding outcomes that take into account cardiometabolic risk factors (glycemic profile, lipid profile, inflammatory markers, and blood pressure). Epidemiological studies(Tarp et al., 2018; Ekelund et al., 2012) have demonstrated an association between physical activity and cardiometabolic risk factors, suggesting that PA is an important modifiable determinant, and that individuals with high levels of PA present a better cardiometabolic profile.

Therefore, the objective ofthe current study aims to (1) systematically review PA interventions using motion sensors (with or without access to mHealth technology) for improving cardiometabolic health in adolescents, and (2)statistically analyze intervention effects to improve cardiometabolic health.

2. Methods

This systematic review was elaborated according to the PRISMA recommendation (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)(Moher et al., 2009)and was registered in PROSPERO (CRD42018105929).

2.1 Search strategy

The databases searched for this systematic reviewwere: PubMed; Scopus; The Cochrane Library; Lilacs; Web of Science; and SPORTDiscus. The search was also performed in clinical trials and the gray literature, and all the searches were conducted in October 2019. No language or publication deadlines restrictions were applied to the initial search, to guarantee the identification of all potentially relevant works.

The MeSH search terms or keywords used were: population (adolescents, adolescence, boy, girl, young people, youth), intervention (exercise, physical activity), and outcomes (smartphone, mobile applications, pedometer, step counter, motion sensor). The reference lists of the articles included in this review were also analyzed to identify any relevant articles. The complete search strategy is available in Supplement 1.

2.2 Eligibility criteria and Selection of studies

The studies were eligible for inclusion if they met the following criteria: i)population: adolescents (12–18yr); ii)study design: pre-experimental or quasi-experimental or randomized controlled trial; iii)type of intervention: structured or unstructured physical activity intervention with motion sensors that provided feedback for self-monitoring (with or without access to mHealth technology); iv)primary outcomes: quantitative assessment of cardiometabolic risk factors (body mass index, waist circumference, glycemic and lipid profile, blood pressure); and v) control group with minimal interventions.

Articles were excluded if presenting any of the following characteristics: (i) observational studies; (ii) physical activity interventions that did not use motion sensors which provided feedback; (iii) adolescents in the control group received an intervention with systematized physical activity (physical exercise, training); (iv) sample composed of children, adults, and/or older adults.

After identification of the articles, the duplicates were removed. Subsequently, two independent reviewers (G.C.S and A.S.N) screened the titles and abstracts, and studies that did not meet the inclusion criteria were excluded. Potentially eligible articles were analyzed by means of full text reading by independent reviewers (G.C.S and A.S.N). Disagreements regarding the inclusion of articles were resolved by consensus or consulting a third reviewer (S.O.P).

2.3 Data Extraction

Data from the included studies were extracted by two independent reviewers (G.C.S and A.S.N), using an EXCEL form. The discrepancies were resolved by consensus or by consulting a third reviewer (S.O.P). The variables extracted were: characteristics of the study (author and year), study design, sample (number of participants, age, and sex), measurement of results, description of intervention, duration of intervention, and main results.

2.4 **Risk of bias**

The risk of bias in each included study was assessed by two independent reviewers (G.C.S and A.S.N). To evaluate the quality of the study, 5 domains of the Cochrane tool were used(Higgins and Green, 2011):sequence generation, allocation concealment, blinding, incomplete outcome data, andselective outcome reporting. Each domain was ranked as low, unclear, moderate or high risk of bias.

2.5 Statistical analysis

The outcomes were changes from baseline to post-intervention in the following variables: body mass index (BMI), body fat percentage(%BF), and waist circumference (WC). Evaluation of the effect of the intervention was based on the difference between the intervention group and the control group. The inverse variance method and the random effect model were used in the meta-analysis, considering the duration of the intervention and type of outcome variable. Mean differences (MD) and 95% confidence intervals were calculated using the Review Manager software (RevMan 5.3)(RevMan, 2014). For the calculation of effect sizes of the mean differences, we used the Cohen16 classification. Statistical heterogeneity was assessed using the Higgins inconsistency test or I2, this statistic describes the percentage of variability in the estimate of the effect attributed to heterogeneity rather than chance, and can be interpreted as follows: mild, acceptable heterogeneity (0% to 25%), moderate heterogeneity (25% - 50 %), and high heterogeneity (> 50%)(Higgins JP, 2003).

3. RESULTS

The electronic search conducted on 18 October, 2019 identified 5,095 articles, of which 91 complete articles were selected for eligibility evaluation (FIGURE 1). After full reading, 79 manuscripts were excluded, totaling 12 articles for the systematic review (Conwell et al., 2010; Ermetici et al., 2016; Kantanista et al., 2014; Lubans et al., 2011; Lubans et al., 2012; Lubans et al., 2016; Mameli et al., 2016; Manley et al., 2014; Martínez López, 2016; Schofield et al., 2005; Staiano et al., 2017; Isensee et al., 2018)and 6 included in the meta-analysis.

We contacted the authors of 5 randomized controlled trials included in the meta-analysis to obtain information on data related to the results, and two authors did not respond to our email.

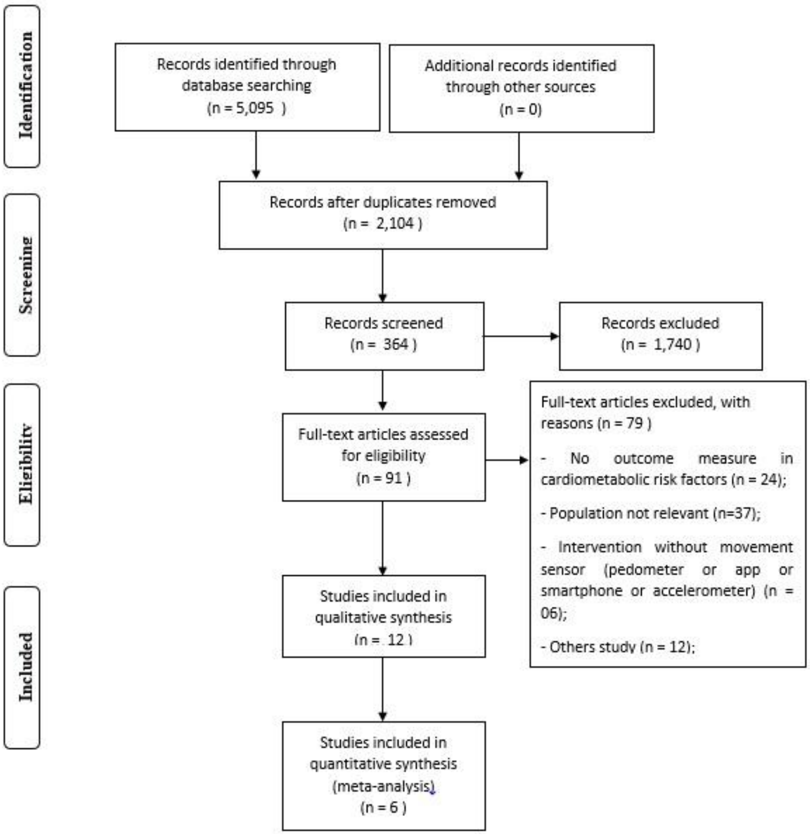

Figure 1. Flow diagram of trial selection, adapted from PRISMA. APP: application.

3.1 Characteristics of the included studies

The characteristics of the included studies are detailed in TABLE 1. The sample sizes of the 12 studies included in the systematic review ranged from 18 to 1,020, totaling 2,850 adolescents. Regarding the design of the studies, seven were randomized clinical trials (RCT)(Isensee et al., 2018; Lubans et al., 2011; Lubans et al., 2012;

Lubans et al., 2016; Mameli et al., 2016; Manley et al., 2014; Martínez López, 2016),three were quasi-experimental(Ermetici et al., 2016; Schofield et al., 2005; Staiano et al., 2017), and two pre-experimental interventions(Conwell et al., 2010; Kantanista et al., 2014). Eight studies included participants of both sexes(Conwell et al., 2010; Ermetici et al., 2016; Isensee et al., 2018; Mameli et al., 2016; Manley et al., 2014; Martínez López, 2016; Schofield et al., 2005; Staiano et al., 2017). In all studies(Conwell et al., 2010; Ermetici et al., 2016; Isensee et al., 2018; Martínez López, 2016; Kantanista et al., 2014; Lubans et al., 2011; Lubans et al., 2012; Lubans et al., 2016; Manley et al., 2014; Schofield et al., 2005; Staiano et al., 2017), the motion sensors promoted PA, and the most commonly used sensor was the pedometer or the spring-levered one. The study by Lubans et al.(Lubans et al., 2016) also used smartphone applications in addition to the pedometer to promote PA, while Mameli et al.(Mameli et al., 2016)used a wristband as a motion sensor. In two studies, general step goals were used to promote changes in PA behavior (for example, reaching 12,000 and 15,000 steps per day for boys and girls respectively)(Manley et al., 2014; Martínez López, 2016) . Components other than motion sensors used in the interventions were: school environment (teachers, counseling, and information)(Ermetici et al., 2016; Isensee et al., 2018; Lubans et al., 2011; Lubans et al., 2012; Lubans et al., 2016; Manley et al., 2014); sessions and/or group meetings(Conwell et al., 2010; Schofield et al., 2005; Staiano et al., 2017); text message(Ermetici et al., 2016; Lubans et al., 2012; Lubans et al., 2016; Mameli et al., 2016); diet(Mameli et al., 2016); and members of the family(Isensee et al., 2018; Conwell et al., 2010; Lubans et al., 2012; Lubans et al., 2016) . The duration of the interventions ranged from 2 months to 2 years. Regarding the control group, 8 studies did not perform any type of intervention for this group(Ermetici et al., 2016; Isensee et al., 2018; Lubans et al., 2011; Lubans et al., 2012; Lubans et al., 2016; Manley et al., 2014; Martínez López, 2016; Schofield et al., 2005), while in one study the control group received a diet intervention, and instructions on PA and sedentary behavior(Mameli et al., 2016), and in another(Staiano et al., 2017) the control group participated in 10 education sessions composed of PA, nutrition and behavioral changes.

With respect to the main results found, 5 studies(Conwell et al., 2010; Ermetici et al., 2016; Isensee et al., 2018; Schofield et al., 2005; Staiano et al., 2017) found an increase in PA, 5 interventions observed a reduction in BMI (kg/m2)(Lubans et al., 2011; Lubans et al., 2012; Mameli et al., 2016; Martínez López, 2016; Staiano et al., 2017)and in BMI z-score(Ermetici et al., 2016; Lubans et al., 2011; Lubans et al., 2012; Lubans et al., 2016; Staiano et al., 2017) . Among the analyzed outcomes, a decrease in the percentage of body fat was reported in two studies(Lubans et al., 2011; Lubans et al., 2012), and a decrease in body weight(Mameli et al., 2016), reduction in relative body mass index(Manley et al., 2014), waist to height ratio(Ermetici et al., 2016), and increased insulin sensitivity(Conwell et al., 2010) .

Table 1. Characteristics of included studies.

Study	Design	Sample	Outcome measures	Reference standard	Intervention description	Duration Intervention	Main results
Conwell et al., (2010)	Pre-experimental (home-based)	*n*= 18 adolescents; Aged: 8-18 years.	PA= Pedometer; Anthropometry/body composition=Weight; Height; BMI; WC; Cardiovascular risk factors= Blood pressure; Lipids and lipoproteins (TG; TC; HDL; LDL; VLDL); SI- insulin sensitivity	BMI > 30 kg/m2 (Cole et al., 2000).	IG= counseling sessions (identify PA preferences and strategies to overcome barriers); pedometer goals of 10% increase from baseline levels); social support (family members).	10 weeks	Statistically significant increases in PA (10 800 ±919 to 13 667±1117) and insulin sensitivity (1.52±0.19 to 2.02* ±0.27) between the baseline and post-intervention. No significant differences in the weight, height, BMI, WC, BP, lipids and lipoproteins.
Ermetici et al., (2016)	non-randomized controlled (quasi experimental) school-based)	*n*= 487 adolescents; IG= 262; CG= 225. Aged = 11-15 years.	PA: questionnaire and pedometer; Anthropometry (weight; height; BMI-z score; Waist circumference-WHtR); Diet indicators: questionnaire;	BMI z-scores using CDC growth (Cole et al., 2000).	IG= Multicomponent intervention (school environment; Reinforcement tools such as textbook; text messages; pedometer-based self-monitoring, encouraging step increase. CG: No intervention	2 years	In adolescents with overweight/obesity, there was an increase in PA (from 9,399±211 to 12,268± 4701 daily steps, P = 0.01). The intervention was associated with a significant difference in BMI z-score between groups (-0.18±0.03, P<0.01) and WHtR (-0.04±0.002, P<0.001). Subgroup analysis with overweight/obesity showed an association between the intervention and the difference in BMI z-score for girls (-0.39; 95% CI [-0.56 to -0.22]) and for boys (-0.22; 95%CI [-0.42 to -0.03]); WHtR for girls (-0.04; 95% [-0.06 to -0.03]) and boys (-0.05 [-0.06 to -0.04]).

Isensee et al., (2018)	RCT (based-school)	n = 1020 adolescents; IG = 649 CG = 371 Aged: 12-15 years.	PA = Question about MVPA (days/week), out-of-school sports activities (hours/week) and Active transport/commuting (minutes/day) BC = BMI (weight and height), WC, Body fat (bioelectrical impedance) and waist-to-height ratio.	BMI calculated (weight/height^2) and converted into the age- and sex-specific percentiles using Cole's (1990).	IG = multi-component intervention: - Individual (pedometer for self-monitoring and interactive user account on the "läuft." homepage - document their steps and experiences); - class (educational and practical lessons, and competitions means of steps/week and to collect creative ideas on how to increase PA in everyday school life and to keep records of these ideas.); - parents (parent-teacher conference to emphasize the importance of physical activity and to support their children in establishing a physically active lifestyle); - school (information material, activity promoting teaching methods, suggestions on how to improve the school environment to stimulate physical activity).	12-week 1-year Follow-up	A significant interaction effect between time and group for all 3 indicators of PA was observed: intervention group showed an increase spent with at least 1 hour of MVPA, while the control group decreased; active commuting and out-of-school sports activities increased significantly in the intervention but not in the control group. In relation to body composition: BMI percentile and body fat increased in both groups, but body fat increased nearly twice in the control; there were statistically significant increases in time*group effect on the waist-to-height in the control adolescents, while the intervention group remained stable.
Kantanista et al., (2014)	Pre-experimental	n = 56 girls; IG = 28; CG = 28 Aged: 16-18 years.	PA = Pedometer (Yamax Digi-Walker SW 701) for 7 weeks. BC = body fat (Bodystat 1500) and BMI;		IG and CG = Pedometer (individual goals pre-determined progressively, from the execution of an additional 10% (in the first week) to 25% (at week 8) in the number of steps.	8 weeks	There were no significant group-by-time interaction effects in biological variables and number of steps per day.
Lubans et al., (2011)	RCT (based school)	n = 100 boys; IG = 50; CG = 50; Aged: 14-15 years	PA = Pedometer (Yamax CW200) for 5 days (4 consecutive school days and 1 weekend day). BC = weight; height; BMI; WC; body fat (Imp™SFB7bioelectrical impedance).	BMI z-scores were calculated using reference centiles (Cole et al., 2000).	IG = multi-component intervention: -Enhanced school sport sessions (PA and nutrition recommendations; structured PA) – 10 x 90 min; -Interactive seminars 3 × 30 min; -Lunch-time physical activity sessions: 8 × 30 min; -Physical activity and nutrition handbooks - 9 weeks; -Physical activity leadership sessions 6 × 30 min; -Pedometers for self-monitoring (6 months) CG = not intervention.	6 months	There were significant group-by-time interaction effects for BMI with mean difference between groups: [−0.8 (−1.2, −0.3)] (p<0.001, d=0.7); and BMI z-score: mean difference between groups:[−0.2 (−0.3, −0.1)] (p<0.001, d=0.7); Significant beneficial effects were found from baseline 6 months for body fat% mean difference between groups: [−1.8 (−3.5, −0.2)] (p< 0.04, d= 0.5). Reduction in the number of participants classified as overweight (20% to 8%) or obese (10% to 8%) in the intervention group.
Lubans et al., (2012)	RCT (based school)	n = 357 girls IG = 178; CG = 179 Aged = 12-14 years.	PA = Actigraph accelerometers (MTI models 7164,GT1M, and GT3X) for 7 consecutive days. BC = weight; height; BMI; WC; body fat (Imp™ SFB7 bioelectrical impedance).	BMI categories were based on BMI z scores (Cole., 2000)	IG = multi-component intervention: -Enhanced school sport sessions (PA and nutrition recommendations; structured PA): 60-80 min; - 3 Interactive seminars; -Lunch-time physical activity sessions; -Physical activity and nutrition handbooks; -Pedometers for self-monitoring; - parent newsletters (4 periods); - Text messaging for social support. CG = no intervention	12 months	Changes in body composition were all in favor of the intervention group, but there were no statistically significant between-group differences. Difference in change: BMI (95% CI) −0.19 (−0.70 to 0.33); BMI z-score (95% CI): −0.08 (−0.20 to 0.04); Body fat%(95% CI): −1.09 (−2.88 to 0.70).

Lubans et al., (2016)	RCT (based school)	n= 361 boys; IG= 181; CG= 180 Aged= 12-14 years.	PA = actigraph accelerometers (model GT3X); BC = BMI; BMI z score and WC.	BMI-z scores were determined using reference centiles (Cole et al., 2000).	IG= ATLAS intervention: -Teachers (workshops and fitness instructor session); -Parent (newsletters- 4 ×); - Students (Researcher-led seminars 3 × 20 min); - Enhanced school sport sessions (PA and nutrition recommendations; structured PA): 20 x 90 min; -Lunch-time physical activity sessions; -Smartphone application and website for physical activity monitoring and motivational messaging (15 weeks); - Pedometers for self-monitoring to set goals to increase their daily steps (17 weeks). CG = received the intervention following the 18-month assessments.	8 months Follow-up = 10 months post-intervention	There was some support for a positive effect among participants who were overweight or obese at baseline (n=129), as demonstrated by a reduction in BMI z-score (mean[95% CI]): - 0.13 [−0.23 to −0.03, p = 0.013], in the intervention group, compared to a smaller reduction among those in the control group -0.06 [-0.16 to 0.05, p = 0.292).
Mameli et al., (2016)	RCT	n= 43 adolescents IG= 16 CG= 14 Aged= 10 – 17 years.	BC = SDS of BMI (standard deviation scores): calculated using Italian reference data (Cacciari, 2006).	BMI ≥95th percentile (Cacciari, 2006)	IG= Mediterranean diet and instruction to practice PA and minimize sedentary activity; wristband (motion sensor) to measure EE; APP (real-time recording of food consumption); SMS (feedback on the diet and PA); CG = Mediterranean diet and instruction to practice PA and minimize sedentary activity.	3 months	Changes in weight and BMI (SDS) were - 0.06 kg (95%CI: 3.29 to 3.14, p = 0.96) for the IG vs. CG. Difference was in fact 0.07 kg (95%CI: 2.81 to 2.96, p = 0.96) and BMI (SDS) 0.01 kg (95%CI: 0.15 to 0.18, p = 0.87) for intervention.
Manley et al., (2014)	RCT	n= 116 adolescents; IG= 55; CG= 61; Aged: 11-13 years.	PA: Pedometer (YamaxDigiwalker 200) for 4 days; BC = BMI; BMI percentile; and relative body mass index (RBMI).	Overweight was defined as a BMI percentile between 85 and 94% (overweight) and BMI ≥95% (obese) (CDC,2000). RBMI =[BMI/(50th percentile BMI on CDC age-gender specific growth chart × 100].	IG= Pedometer (girls to achieve at least 12,000 and boys 15,000 steps each at school). Teachers (encourage the students and educate regarding the benefits of physical activity) CG = no intervention	12 week	Intervention group 8.71 reduction in RBMI compared to a 1.78 reduction in the control group.
MartínezLópez, (2016)	RCT	n= 102 adolescents; IG1 = 31; IG2 = 37; CG = 34; Aged=13.70± 1.47 years	PA = pedometer (Omron HJ-152-E); BC = BMI (weight and height);	BMI reference (Sobradillo, 2004).	IG 1 and 2 = girls to achieve at least 10,000 and boys 12,000 steps per day. CG = no intervention	6 weeks	Statistically significant reduction in BMI (27.95 ± 2.86 to 27.58 ± 2.91 kg/m^2, P= 0.000) in the IG and increase in the CG (27.83 ± 3.91 to 28.18 ± 3.76, P= 0.000) between the baseline and post-intervention.
Schofield et al., (2005)	quasi-experimental	n = 85 girls; IGP = 27; IGM = 28; CG = 30; Aged= 15 – 18 years.	PA = 4-days of pedometer seald (SW700 Yamax Digiwalker) and PA questionnaire. BC = BMI (weight and height) and WC; Blood pressure: Omron monitor.	BMI was determined using age-specific cut points for overweight and obesity (Cole, 2000).	Intervention (IGP and IGM) involving goal setting and self-monitoring using either time-based PA goals or step based PA goals. Weekly meetings to discuss PA, goals and barriers. Weekly meetings to discuss PA, goals and barriers. CG = no intervention.	12 weeks	Step-based intervention group significantly increased PA from baseline. There were no significant changes in any group for BMI.
Staiano et al., (2017)	quasi-experimental (family-based)	n = 105 adolescents; IGP = 25; IGP+G = 56; CG = 24 Aged = 8-17 years.	PA = Pedometer (Omron HJ-324U); BC = BMI (weight and height).	BMI z-score was calculated from the CDC (2016).	The groups received 10 sessions of 90 min. (PA, nutrition, and behavioral modification); IGP = session + pedometer for self-monitoring; IGP +G = session + pedometer with individualized step goals (500 steps/day).	10 weeks	IGP +G had a significantly greater reduction in weight (p = 0.045), BMI (p = 0.017), and BMI z-score (p = 0.012), compared with the CG. IGP+G increased on average 1185 (425) daily steps and IGP reduced by 162 (620) daily steps from baseline.

BC: body composition; BMI: body mass index; EE : energy expenditure; CG: control group; IG: intervention group; IGP+G: pedometer intervention group with goals; IGP: pedometer intervention group; MVPA: moderate to vigorous physical activity; PA: physical activity; RBMI: ; RTC: WC: waist circumference.

3.2 Risk of bias

Figures 2 and 3 show the assessment of risk of bias for the 12 included studies. Five studies presented a high risk of bias in the randomization domain(Conwell et al., 2010; Ermetici et al., 2016; Kantanista et al., 2014; Schofield et al., 2005; Staiano et al., 2017). Three studies did not describe how concealment of allocation was performed(Lubans et al., 2011; Martínez López, 2016; Schofield et al., 2005) and were classified as unclear risk of bias. Five studies had a low risk of bias in the allocation(Isensee et al., 2018; Lubans et al., 2012; Lubans et al., 2016; Mameli et al., 2016; Manley et al., 2014), since concealment was performed by hidden envelopes or a researcher not involved in the study, or by software. Two studies were classified as low risk of bias in the blinding domain(Lubans et al., 2012; Lubans et al., 2016)and five as unclear risk of bias(Isensee et al., 2018; Mameli et al., 2016; Manley et al., 2014; Schofield et al., 2005; Staiano et al., 2017), as these studies did not adequately inform whether participants or evaluators were appropriately blinded.

Regarding the domain incomplete results, 9 studies were classified as low risk of bias(Kantanista et al., 2014; Lubans et al., 2011; Lubans et al., 2012; Lubans et al., 2016; Mameli et al., 2016; Manley et al., 2014; Schofield et al., 2005; Isensee et al., 2018). Four studies were assessed as having an unclear risk of bias for reporting selective results, as results were not reported in detail in the paper (Ermetici et al., 2016; Kantanista et al., 2014; Schofield et al., 2005; Staiano et al., 2017) . Five studies presented a low risk of bias(Lubans et al., 2012; Lubans et al., 2016; Mameli et al., 2016; Manley et al., 2014; Isensee et al., 2018), one study an unclear risk(Lubans et al., 2011), and six a high risk of bias(Conwell et al., 2010; Ermetici et al., 2016; Kantanista et al., 2014; Martínez López, 2016; Schofield et al., 2005; Staiano et al., 2017) .

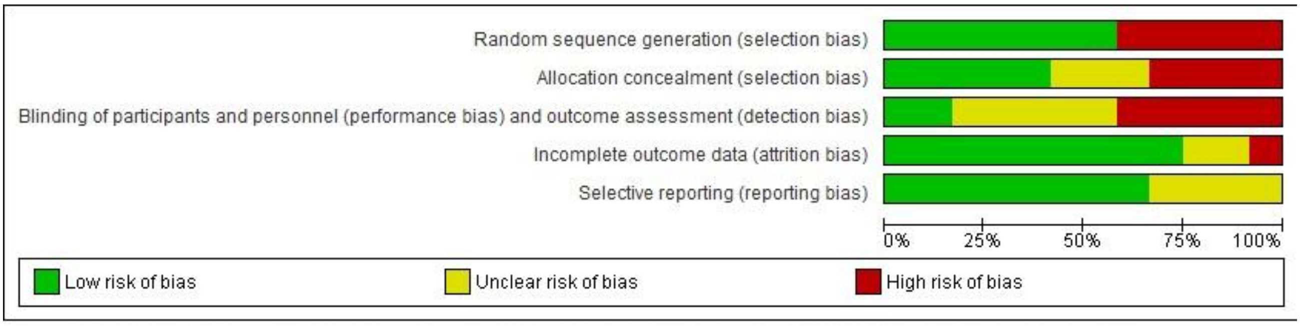

Figure2. Risk of bias graph: review authors' judgments on each risk of bias item presented as percentages across all included studies.

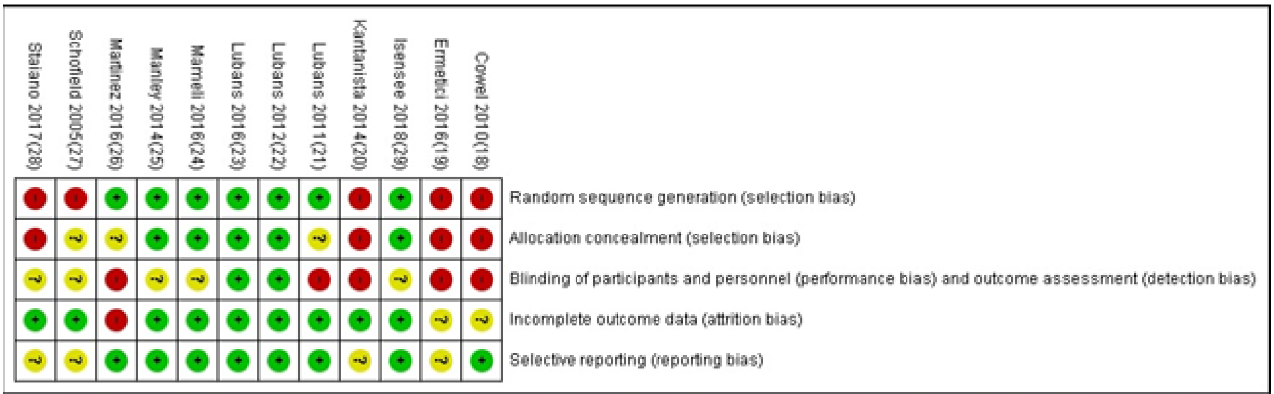

Figure 3. Risk of bias summary: review authors' judgments on each risk of bias item for each included study. Green symbols represent a low risk of bias, yellow symbols represent an unclear risk of bias, and red symbols a high risk of bias.

3.3 EFFECTS OF INTERVENTIONS

3.3.1 Effects on body mass index (BMI)

All included studies: 3 to 12 months of intervention

All clinical trials(Isensee et al., 2018; Lubans et al., 2011; Lubans et al., 2012; Lubans et al., 2016) included in the meta-analysis evaluated BMI (kg/m2) and reported changes between baseline and post-intervention. The meta-analysis of random effects did not demonstrate a statistically significant difference in the mean of the difference (MD) in BMI between the intervention and control groups (MD= - 0.63, 95% CI= -1.28 to 0.01, P= 0.06; 1878 participants; 4 studies), with high evidence of heterogeneity ($I2$ =79%).

The magnitude of the difference (- 0.63) can be interpreted as a "moderate" effect according to the Cohen effect size classification(Cohen, 1988) .

Studies: 3 months of intervention

Two studies(Lubans et al., 2011; Isensee et al., 2018)evaluated BMI after 3 months of intervention, no significant decrease was found for the intervention group compared to the control group (MD= - 0.08, 95% CI= -0.19 to 0.02, *P*= 0.11; 1160 participants; 2 studies;) no evidence of heterogeneity (*I2* =0%) (FIGURE 4).

Studies: 6 to 12 months of intervention

The differences in BMI means were statistically significant in relation to the studies(Lubans et al., 2011; Lubans et al., 2012; Lubans et al., 2016) that performed interventions lasting more than six months (MD= - 0.96, 95% CI= -1.65 to -0.27, *P*= 0.006; 818 participants; 3 studies), with evidence of mild heterogeneity (*I2* =19%). This indicates a moderate and significant effect of PA interventions using motion sensors on BMI in adolescents. All randomized controlled trials found a decrease in BMI for the intervention group compared to the control.

Studies: Follow-up

Three studies performed a follow-up of the intervention(Isensee et al., 2018; Lubans et al., 2012; Lubans et al., 2016), the magnitude of the difference was -1.12, but it was not statistically significant (MD= - 1.12, 95% CI= -3.13 to 0.88, *P*= 0.27; 1647 participants; 3 studies), with high heterogeneity (*I2* =77%).

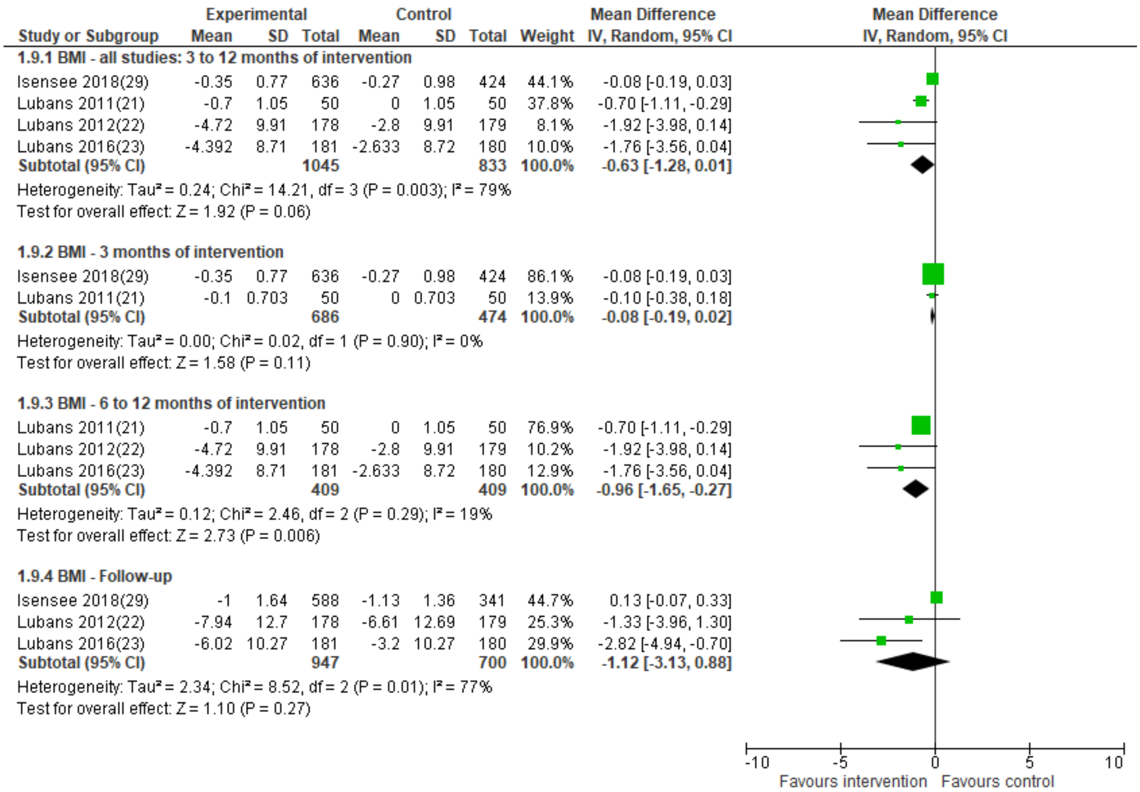

Figure 4.Forest plot of the effect of motion sensors – determined physical activity interventions versus control on body mass index (kg/m2). CI: confidence interval, IV: inverse variance, SD: standard deviation.

3.3.2 Effects on body fat

All included studies: 3 to 12 months of intervention

Body fat was analyzed in all studies(Lubans et al., 2011; Isensee et al., 2018; Lubans et al., 2012; Lubans et al., 2016) included in the meta-analysis of random effects, showing that there were no statistically significant differences between the means of BF (MD= -1.51, 95% CI= -3.17 to 0.15, *P*= 0.08; 1808 participants; 4 studies; certainty of evidence very low), with high heterogeneity (*I2* = 79%). The certainty of evidence was classified as very low as there was a risk with respect to blinding of the participants, wide confidence intervals, and concerns about the heterogeneity of the data.

Studies: 3 months of intervention

Two studies verified body fat after 3 months of intervention, and no significant difference was found for BF (MD= -0.79, 95% CI= -2.69 to 1.10, *P*= 0.41; 1090 participants; 2 studies), with high heterogeneity (*I2* = 85%).

Studies: 6 to 12 months of intervention

A meta-analysis was performed of interventions over six months for body fat, three studies were included(Lubans et al., 2012; Lubans et al., 2016; Lubans et al., 2011), demonstrating a significant decrease in BF in the adolescents belonging to the intervention group (MD= -2.11, 95% CI= -3.26 to -0.96, *P*= 0.0003; 818 participants; 3 studies), with no evidence of heterogeneity (*I2* =0%) (FIGURE 5).

Studies: follow-up

Three studies performed a BF evaluation at follow-up (10 to 12 months post intervention), and the meta-analysis of random effects demonstrated a magnitude of large effect (-1.13), although not significant (MD= -1.13, 95% CI= -3.90 to 1.64, *P*= 0.42; 1599 participants; 3 studies), with high heterogeneity (*I2*=81%).

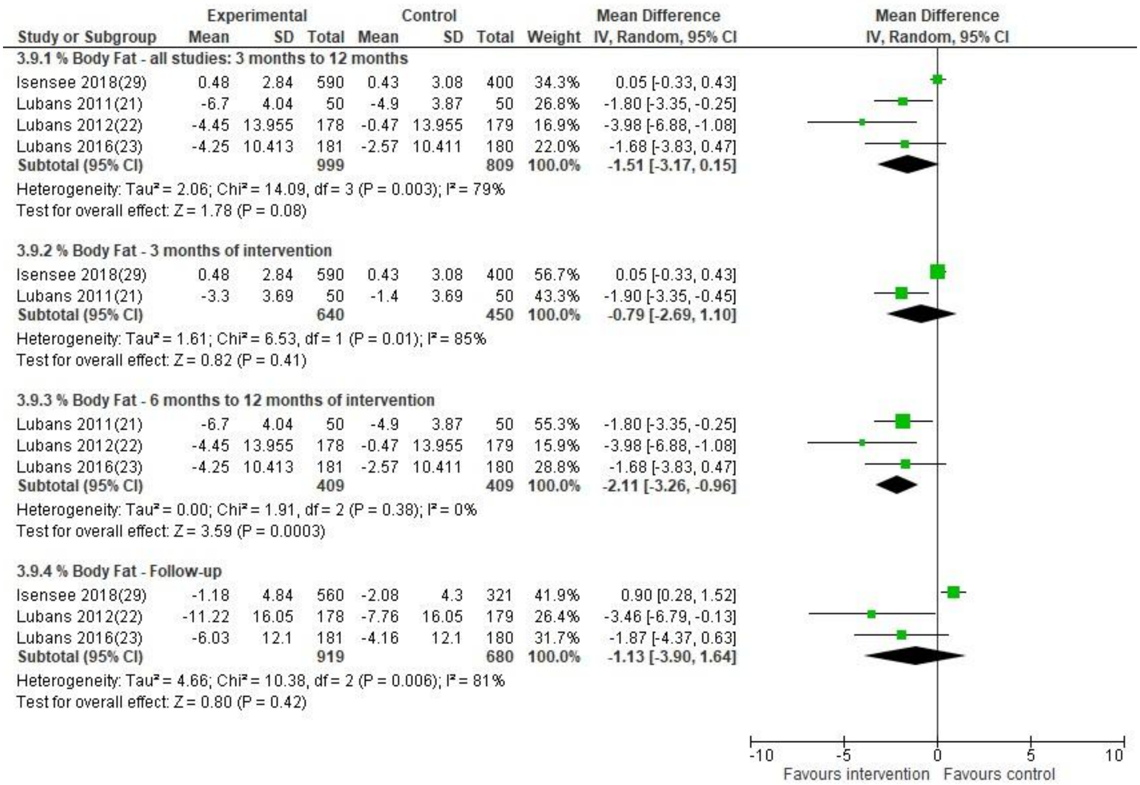

Figure 5.Forest plot of the effect of motion sensors – determined physical activity interventions versus control on body fat (%). CI: confidence interval, IV: inverse variance, SD: standard deviation.

3.3.3 Effects on waist circumference

All included studies: 6 to 12 months of intervention

A meta-analysis of random effects including two randomized controlled trials (Lubans et al., 2011; Lubans et al., 2016) did not demonstrate a statistically significant difference in waist circumference (MD= -1.62, 95% CI= -7.94 to 4.69, *P*= 0.61; 461 participants; 2 studies), with high evidence of heterogeneity (*I2* =73%) (FIGURE 6).

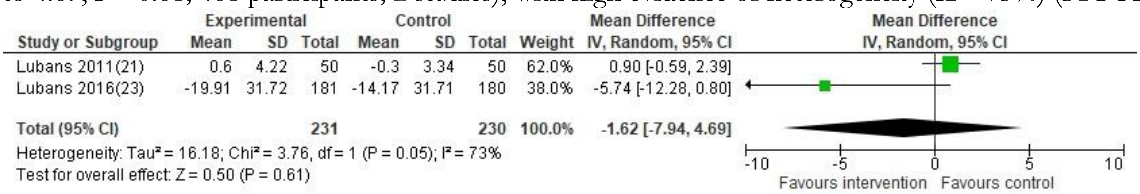

Figure 6. Forest plot of the effect of motion sensors – determined physical activity interventions versus control on waist circumference (cm). CI: confidence interval, IV: inverse variance, SD: standard deviation.

4. DISCUSSION

The aim of our review was to synthesize the available evidence surrounding of physical activity intervention using motion sensors for improving cardiometabolic health in adolescents. The findings of the review indicate that (1)the most commonly used motion sensor was the pedometer, (2)the majority of the studies included multicomponent in the intervention protocol, and (3) the main outcome of these studies weresummarized in body composition. Our meta-analysis results suggest that interventions lasting between 6 and 12 months promoted a significant reduction in BMI and body fat percentage.

We have identified that the most studies used reduction in BMI(Lubans et al., 2011; Lubans et al., 2012; Lubans et al., 2016; Martínez López, 2016), BMI z-score(Ermetici et al., 2016; Lubans et al., 2011; Lubans et al., 2012; Lubans et al., 2016), BMI (SDS)(Mameli et al., 2016) as health-related outcomes because the improvements in body composition may be associated with additional benefits in cardiometabolic health (insulin sensitivity, total cholesterol/high-density lipoprotein ratio and blood pressure), however, it is important to assess other outcomes such as cardiometabolic risk markers.

Cardiovascular risk parameters were only investigated in one of the included studies; the result of this study showed insulin sensitivity improvement after 10 weeks of intervention with goal-setting and self-monitoring through pedometer use and family support (Conwell et al., 2010).

The current systematic review found that one studies used motion sensors with the goal of promoting an active lifestyle. Despite physical activity being considered as an important issue in cardiometabolic health, more than a half of the global population and adolescents are considered insufficiently active(Kohl et al., 2012; Hallal et al., 2012).Epidemiological studies(Ekelund et al., 2012; Tarp et al., 2018) have shown a positiveassociation between higher physical activity levels and lower cardiometabolic health. So, the use of the motion sensors which supply feedback become an effective strategy to increase physical activity through of the self-monitoring resulting improvements in cardiometabolic profile.

The studies of Conwell(Conwell et al., 2010), Kantanista(Kantanista et al., 2014), Manley(Manley et al., 2014), Martínez Lopes(Martínez López, 2016), Schofield(Schofield et al., 2005), and Staiano(Staiano et al., 2017) worked with setting goals through the number of steps to be achieved, while six other studies(Ermetici et al., 2016; Isensee et al., 2018; Lubans et al., 2011; Lubans et al., 2012; Lubans et al., 2016; Mameli et al., 2016) used the sensor only for the purpose of self-monitoring. In all the interventions, PA was the main component, even though there were methodological differences in setting the goals and the time of use of the motion sensor, the results suggested that the promotion of regular practice of PA resulted in improvements in body composition. The use of motion sensors (pedometer, wristbands, and smartphone applications) resulted in feedback, which was essential for adolescents to be aware of their habitual behavior and, from this, improve their level of PA(Salawi et al., 2014; Zolotarjova et al., 2018) .

The pedometer was the most commonly used motion sensor in the studies, both to assess physical activity, as well as part of a strategy to facilitate self-monitoring. The pedometers used are different as for the brands, models and internal mechanism (piezoelectric and spring-levered), but despite this difference, the pedometers used in the articles included in this current review are validated as a suitable tool for step monitoring and recognized for its high accuracy.

Most of the studies included other components in the intervention protocol, as well as PA, such as: school (school environment, teachers)(Ermetici et al., 2016; Lubans et al., 2011; Isensee et al., 2018; Lubans et al., 2012; Lubans et al., 2016; Manley et al., 2014), counseling sessions on healthy habits(Conwell et al., 2010; Schofield et al., 2005; Staiano et al., 2017), diet(Mameli et al., 2016), and family involvement(Isensee et al., 2018; Conwell et al., 2010; Lubans et al., 2012; Lubans et al., 2016). Multidisciplinary programs and interventions are considered effective and play a central role in behavioral modification in adolescents, especially in individuals with excess weight.

Regarding the outcomes obtained, four of the seven RCTs included in the current review were part of the meta-analysis, since Martinez's study(Martínez López, 2016) presented a high risk of bias, and two authors(Mameli et al., 2016; Manley et al., 2014) did not send the necessary information regarding the results so that they could be included in the meta-analysis. All the randomized clinical trials were predominantly school-based. Significant statistical heterogeneity was detected among the 4 trials(Lubans et al., 2011; Lubans et al., 2012; Lubans et al., 2016; Isensee et al., 2018), however, when analyzing studies with similar methodological characteristics, (specifically the duration of intervention) the heterogeneity was reduced.

The meta-analysis of these studies revealed that interventions lasting between 6 and 12 months promoted a significant reduction in BMI and % body fat in the intervention group compared to the control, being the mean difference of -0.96, -0.27 and -2.11, respectively (FIGURE 3, 4).

These randomized controlled trials were guided by social cognitive theory and included the following components: enhanced school sport sessions, interactive seminars, nutrition workshops, lunch-time physical activity sessions, handbooks and pedometers for self-monitoring, parent newsletters and text messaging for social support.

However, when analyzing the 3-month interventions, magnitudes of trivial and moderate effects were verified for the BMI and %BF, respectively, with no statistically significant differences. Both programs used strategies with multicomponent approach that is school-based and included social support from peers and parents, goal-setting and self-monitoring through pedometer use. This evidence suggests that physical activity interventions lasting more than 6 months are necessary to result in changes in body composition, and thus facilitate the prevention of obesity in this population.

The results found in this review on the physical activity interventions using motion sensors on cardiometabolic risk factors were summarized as body composition outcomes (BMI, body fat, and waist circumference), while just the Conwell pre-experimental study(Conwell et al., 2010) evaluated other markers besides body composition, such as lipid profile, blood pressure, and insulin sensitivity. This limitation on metabolic parameters observed in our study was also found in a recent review (Zolotarjova et al., 2018) of studies on children and adolescents with morbid obesity, where cardiovascular risk parameters were only investigated in three of the included studies which approached a specific population (obese adolescents).

Knowing that pediatric obesity is increasing, and that weight and body fat reduction are important factors in decreasing the immediate risks (change in metabolic profile) and those in the long term (diabetes mellitus, insulin resistance, cardiovascular diseases), evaluations of other outcomes besides anthropometry, related to cardiometabolic risk factors, are necessary in future studies(AHA, 2007) .

The strength of our review include the meta-analysis of the effect of the intervention on physical activity using motion sensor on cardiometabolic health in adolescents. Despite the strengths of the present study, there are limitations. The main limitation of this review was the small number of scientific studies identified eligible for inclusion. Second, the effect of the interventions is the result of the combination of several components. However, studies have shown that interventions with multi-components are more effective.

5. Conclusion

This systematic review highlights that the most commonly used motion sensor in intervention studies for physical activity promotion was the pedometer. The majority of strategies for physical activity interventions involving adolescents include: self-monitoring of physical activity, nutrition education sessions, physical education classes, and family involvement. Based on the interpretation of the evidence from the included trials, physical activity interventions lasting more than 6 months promoted weight loss and decreased body fat percentage. However, we point out the lack of studies using motion sensors in adolescents addressing the cardiometabolic profile as an outcome variable.

6. Perspectives

This is the first meta-analysis evaluating the effect of physical activity interventions using motion sensors oncardiometabolic health in adolescents. The interventions lasting more than 6 months promoted reduction in BMI and body fat, but no study evaluated metabolic biomarkers outcome. Regarding these findings, it is suggested that future randomized controlled trials using motion sensors must explore variables related to the metabolic profile (glycemic profile, lipid profile, inflammatory markers, and blood pressure). Randomized clinical trials should also clearly state the reasons for drop-outs and to follow the guidelines of CONSORT 2010. In addition, research is needed to assess the impact of physical activity intervention strategies that promote behavioral changes in adolescents, considering the known barriers and facilitators in this population.

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