

Changes in physical activity behavior in children and adolescents: a systematic review and meta-analysis based on a trans-theoretical model

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Abstract. – OBJECTIVE: This article presents a systematic review and meta-analysis of cross-sectional studies of physical activity (PA) behavioral changes in children and adolescents based on the trans-theoretical model (TTM). The main purpose is to test the rationality of TTM and the secondary purpose is to analyze whether PA can effectively identify the stages of change.

MATERIALS AND METHODS: The databases CNKI, Wan-Fang, VIP, WOS, PubMed, and EBS-CO were searched by computer. Two researchers independently reviewed the literature, extracted data, and evaluated the quality of the literature. Stata 23.0 software was used for statistical analysis.

RESULTS: A total of 17 articles of medium and high quality were included in the meta-analysis. First, the behavior changes of PA of children and adolescents are related to the process of change (POC), self-efficacy (SEI), and decisional balance (DBL). The POC, SEI, and DBL have obvious stage characteristics. Second, with increasing intensity of PA, the degree of discrimination of stage of change (SOC) also improved, but PA could not still fully distinguish each stage.

CONCLUSIONS: It is suggested that follow-up studies should compare the stages of change of different criteria by comprehensive behavioral data, exercise willingness, and exercise habits. Furthermore, it is recommended that more studies use longitudinal surveys or experimental interventions to test the rationality of TTM. It is suggested that the follow-up study design more standardized measurement tools to explore the change in PA behavior of children and adolescents.

Key Words:

Trans-Theoretical model (TTM), Physical activity, Behavior change, Stage of change, Children and adolescents.

Introduction

Physical activity (PA) refers to any body activity caused by energy consumption caused by skeletal muscle contraction¹. PA is good for everyone's health and happiness. Some benefits will appear immediately after activity, and some will accumulate over time². Insufficient PA is a risk factor for chronic noncommunicable diseases such as obesity, hypertension, and diabetes, which not only negatively affects the physical health of adolescents, but also exacerbates their health risks in adulthood³. The World Health Organization (WHO) recommends that school-aged children and adolescents accumulate at least 60 minutes of moderate-to-vigorous PA (MVPA) per day⁴. Although the health benefits of PA have become common sense, the problem of insufficient PA in children and adolescents is still prominent⁵⁻⁷. Therefore, it is imperative to develop effective measures to promote PA.

Exercise psychology provides many theoretical models for explaining, predicting, and intervening PA behavior of children and adolescents, among which the trans-theoretical model (TTM) is considered to be a widely used stage model. TTM was proposed by Prochaska and Diclements⁸ in the study of self-change in the process of smoking cessation of smokers. The theory organically integrated 18 main theories of psychotherapy and behavior change and gradually evolved into a theoretical system that systematically studies individual behavior changes. It is widely used in various fields of health promotion. TTM consists of four elements: the stage of change (SOC), process of change (POC), self-efficacy (SEI), and decisional ba-

lance (DBL). The SOC is the core structure of TTM, and it is believed that the change in individual behavior goes through 5 stages: pre-contemplation (PC), contemplation (C), preparation (P), action (A) and maintenance (M)⁸. The SOC establishes a temporal connection between intention and behavior and points out the dynamic nature and direction of individual behavior change⁹. The SOC is the cognitive, emotional, and behavioral strategies adopted by individuals to change sedentary behavior (SB), including 10 POCs of cognition and behavior. The SEI of TTM includes two latent variables: environmental temptations and self-confidence⁹. Environmental temptations refer to the degree of individual desire to participate in physical activities in difficult situations^{10,11}. Self-confidence refers to the degree of self-confidence in the individual's ability to actively respond to health problems in a specific situation. DBL refers to the trade-off between the positive benefits (pros) and negative obstacles (cons) of the actions taken during the process of individual stage changes. The DBL is closely related to the SOC. Individuals in the PC and C stages usually think that the cons of PA outweigh the pros; individuals in the P stage usually think that the pros and cons of PA are basically balanced; individuals in the A and M stages usually think that the pros of PA are greater than cons^{9,12}.

PA is a participation behavior that includes work, home tasks, transportation, and recreational activities¹³. PA is not a must-do activity, but it does require adequate time. PA is a process that requires individuals to make a balanced decision and eventually adapt to the benefits and challenges of PA¹⁴. Because of the uniqueness and complexity of PA, the transformation process is not linear, but rather a dynamic one that fluctuates and reciprocates between stages. As a result, a more thorough theoretical explanation is required. TTM is a comprehensive behavior change model, which proposes that behavior change is a nonlinear, dynamic, and complex process and emphasizes targeted interventions according to the stage of the behavior group. This is also the reason why some researchers^{15,16} suggest using TTM to study the PA promotion program. The latest systematic review^{17,18} proves that TTM-based targeted intervention strategies are helpful for individual stage promotion and improvement of PA. Regarding whether targeted interventions are better than traditional behavior-oriented interventions, Spencer et al¹⁹

reviewed 15 studies and found that more than half of the studies indicated that targeted interventions were more effective. TTM is the most widely used stage model by researchers, and a large amount of evidence has been accumulated in the study of PA in children and adolescents. However, the application of TTM has been questioned to varying degrees. The main problem is that the relationship between internal structural elements is still unclear⁹, which will affect the formulation and implementation of subsequent intervention strategies. What factors in TTM promote the transition to PA in children and adolescents? Can PA based on self-report or objective measurement effectively verify the SOC? No systematic analysis of TTM has been found in the field of PA in children and adolescents. Therefore, we systematically recovered the main results of TTM in PA practice in children and adolescents, explored the transition factors of PA stages in children and adolescents through a meta-analysis, and verified the effectiveness of PA in identifying SOC, to provide evidence support for the formulation of follow-up intervention strategies.

Materials and Methods

This study strictly followed the PRISMA 2020 statement^{20,21} reporting and writing search strategy, inclusion criteria, data extraction, quality assessment, and mathematical statistics.

Literature Search Strategy

Take "TTM", "stage of change", "process of change", "self-efficacy", "decisional balance" and "physical activity", "exercise", "sedentary" as search terms, searched in CNKI, Web of Science (WOS), PubMed, SPORTDiscuss. The search period is from the establishment of the database to April 2022.

Literature Inclusion and Exclusion Criteria

Literature inclusion criteria:

1. The subjects were children and adolescents.
2. The study content is an empirical study to test the internal structural relationship of TTM and verify the validity of the SOC.
3. The study design was a cross-sectional study.
4. Outcome variables include the SOC, POC, SEI, DBL, and PA.

Literature exclusion criteria:

1. Reviews, abstracts, letters, comments, etc.
2. Literature for which comparative data between groups cannot be obtained.
3. Literature that is not supported by the SOC, but involves single elements such as SEI or DBL.
4. For the literature published repeatedly by the same objects, only the one with a higher quality evaluation was included.

Two researchers independently screened the literature according to the inclusion and exclusion criteria, in the order of title, abstract, chart, and full text. The other two researchers conducted a secondary evaluation and if there were disagreements, group discussions were held to jointly decide.

Literature Data Extraction

This study extracted data from the literature according to the guidelines for systematic review in the field of health care developed by York University²². The extracted content includes the first author, publication time, subject characteristics (sample size, nationality, age, proportion of female), stage algorithm, regular PA criteria, and outcome variables (SOC, POC, SEI, DBL, PA). Two researchers independently extracted data from the literature and two other researchers conducted a secondary evaluation of the extraction results. If there was a dispute, the decision was made through group discussion.

Literature Quality Evaluation

The quality of the included literature was assessed using the STROBE statement^{23,24}, which included 22 items covering the title, abstract, introduction, methods, results, and discussion of the article. The STROBE statement provides guidance for researchers on how to improve the quality of observational studies and provides a methodological quality assessment tool for systematic reviews and meta-analysis. Two researchers independently made judgments based on the evaluation tools and if there were serious disagreements, they were discussed in groups.

Mathematical Statistics

This study used Stata 23.0 software (StataCorp LLC, College Station, TX, USA) for statistical analysis. The effect size is expressed as the standardized mean difference (SMD), and the 95% confidence interval (CI) is used to express the estimated interval of the population parameter constructed by the sample statistics. If the SMD

is less than 0.2, it is considered a very small effect size; if the SMD is between 0.2 and 0.5, it is considered a small effect size; if the SMD is between 0.5 and 0.8, it is considered a medium effect size; if the SMD is greater than 0.8, it is considered a large effect size²⁵. Select a combined effect model for the main effects test by heterogeneity test. The sources of heterogeneity were discussed by multivariate meta-regression analysis. The bias test of the publication of the literature was carried out using Egger's linear regression analysis. The literature sensitivity analysis was carried out by the "metainf" command. Q test and I^2 statistics were used to test heterogeneity between studies. With reference to previous study²⁶, we judged $I^2 < 50%$, $p > 0.1$ as a large heterogeneity among the included studies and used a fixed effects model for analysis; $I^2 \geq 50%$, $p \leq 0.1$ as a small heterogeneity among the included studies and used a random effects model for analysis.

Results

Literature Search and Screening Results

A total of 8,743 articles were retrieved and 4,814 articles were obtained after being imported into Endnote X9 software. Through literature selection, 17 articles were finally included. The literature screening process is shown in Figure 1.

Literature Data Extraction and Quality Evaluation Results

A total of 17 articles were included in the meta-analysis (Table I), and the publication years were 1998 to 2021. The meta-analysis included relevant studies from 11 countries. China²⁷⁻²⁹ and Canada³⁰⁻³² included 3 studies each; Korea^{33,34}, Spain^{35,36} and Brazil³⁷ included 2 studies each; Belgium³⁸, Poland³⁹, Germany⁴⁰, Ireland⁴¹, Mexico⁴², and the United States⁴³ included 1 study each. The article of Reis et al³⁷ included a discussion of the structural relationship of different genders, so a total of 18 studies were included. A total of 18,768 children and adolescents were included in the meta-analysis, and the proportion of female was 0.0%³⁷-100.0%⁴¹. The sample size of the included studies ranged from 285⁴² to 5,931³⁸. 14 studies^{27-37,39,41,43} used forced discrete measurement to evaluate stages of PA changes in children and adolescents; 3 studies^{38,40,42} used progressive stage measurement to evaluate stages of PA changes in children and adolescents. The forced discrete measurement mainly uses

the SOC questionnaire prepared by Marcus et al⁴⁴ to evaluate children and adolescents. The 5 items of the questionnaire correspond to the 5 stages of behavior change respectively, and the subjects are required to choose the most appropriate one to reflect the current exercise stage. Progressive stage measurement requires subjects to mark “yes/no” on the following statements and then define the stage in which they are in according to the algorithm shown in Table II⁴². In the aforementioned stage algorithm, 9 studies^{27,28,33,37,39,40,42-43} defined criteria for regular PA, and the criteria for regular PA varied significantly between studies. The regular criteria for PA consist of frequency, time and intensity, and changes as the scientific evidence for the health benefits of PA is updated, from the early American College of Sports Medicine (ACSM) “3 times / week, <20 minutes / time, with shortness of breath and sweating” to the UK-HEA recommendation of “5 days / week, accumulated

MVPA ≥ 60 min/time^{240,45}. The quality assessment of the included studies was moderate to high (15⁴²-21⁴³), with a median of 18^{30,33,35,36,39}. The main reasons for the reduction of the quality evaluation grade are that the sample size is not calculated, the recruitment method and sampling method of subjects are not described, the criteria for regular PA are not defined in the SOC, the effect size and other statistics to judge the comparison effect between groups are not presented, the influence of potential deviation is not considered, and the universality (external validity) of the research results is not discussed.

Meta-Analysis Results

The relationship between the SOC and cognitive processes

In this meta-analysis, 5 studies^{28,30,34,39,40} were included to explore the relationship between

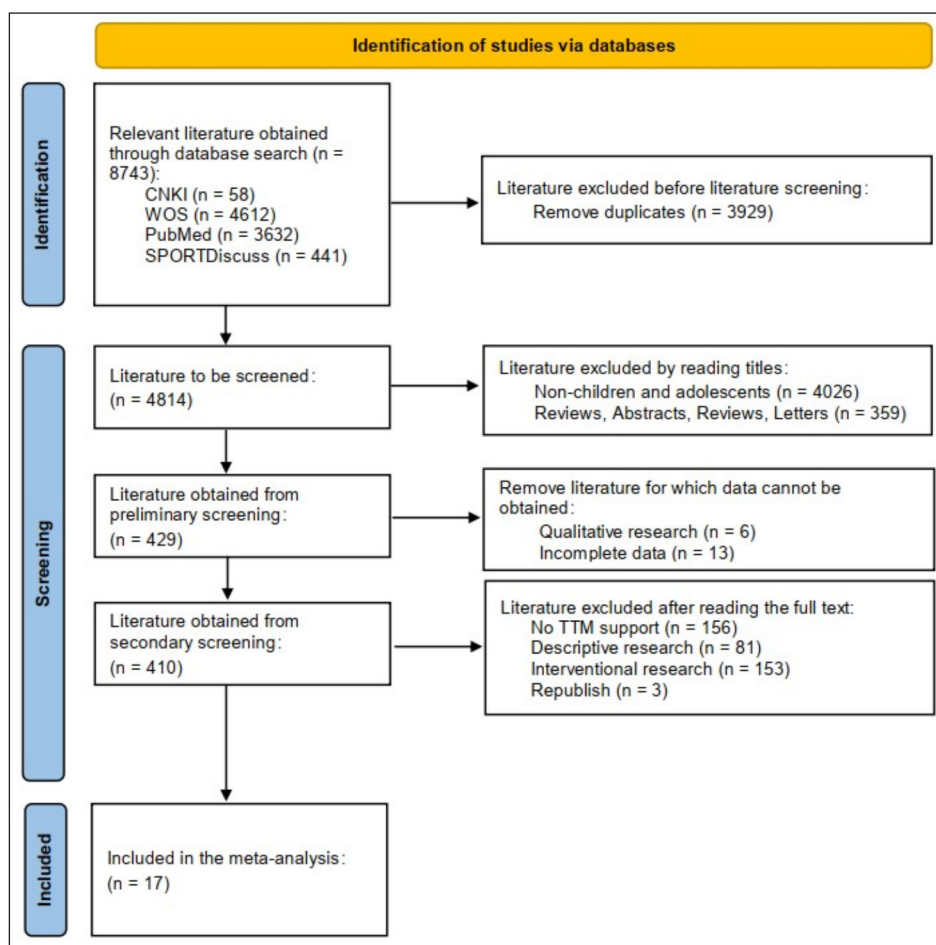


Figure 1. Literature screening flowchart

Table I. Basic characteristics of included studies.

Included studies	Subject characteristics				Stage algorithm	Regular pa criteria	Outcomes					Quality
	Sample size	Country	Age	F%			SOC	POC	SEI	DBL	PA	
Fang et al ²⁷ , 2006	1129	China	15.4	49.4%	①	3 times/week, ≥ 20 min/time, with shortness of breath and sweating	√		√	√		16
Fang ²⁸ , 2011	899	China	15.9 ± 1.3	56.0%	①	3 times/week, ≥ 20 min/time, with shortness of breath and sweating	√	√				19
Yi et al ²⁹ , 2014	1508	China	13.9 ± 1.0	50.5%	①	N/A	√		√	√		16
Nigg et al ³⁰ , 1998	819	Canada	15.0 ± 1.2	48.7%	①	N/A	√	√	√	√		18
Lee et al ³¹ , 2001	819	Canada	15.0 ± 1.2	49.0%	①	N/A	√				√	17
Berry et al ³² , 2005	311	Canada	15-17	43.4%	①	N/A	√		√	√	√	19
Kim ³³ , 2004	671	South Korea	15.8	47.4%	①	3 times/week, ≥ 30 min/time	√		√	√		18
Reis et al ³⁴ , 2005 ^a	278	Brazil	14-17	0.0%	①	MPA: ≥ 5 times/week, ≥ 30 min/time or VPA: ≥ 3 times/week, ≥ 20 min/time	√		√			17
Abarca-Sos et al ³⁵ , 2017	1618	Spain	14.5 ± 1.3	45.36%	①	N/A	√		√		√	18
Planas et al ³⁶ , 2020	372	Spain	12-16	44.9%	①	N/A	√			√		18
Reis et al ³⁷ , 2005 ^b	210	Brazil	14-17	100.0%	①	MPA: ≥ 5 times/week, ≥ 30 min/time or VPA: ≥ 3 times/week, ≥ 20 min/time	√		√			17
Bourdeaudhuij et al ³⁸ , 2005	5931	Belgium	14.8 ± 1.9	61.0%	②	N/A	√		√	√	√	20
Sas-Nowosielski et al ³⁹ , 2007	1251	Poland	17.3 ± 0.9	65.2%	①	MPA: ≥ 3 times/week, ≥ 30 min/time, excluding PE lessons	√	√	√	√		18
Bucksch et al ⁴⁰ , 2008	588	Germany	15.0 ± 0.7	49.5%	②	≥ 5 days/week, accumulated MVPA ≥ 60 min/time	√	√	√	√		19
Burns et al ⁴¹ , 2014	871	Ireland	15.3 ± 1.8	100.0%	①	N/A	√		√	√		20
Hwang et al ³⁷ , 2011	851	South Korea	16.0	43.7%	①	N/A	√	√				16
Zamarripa et al ⁴² , 2019	285	Mexico	16.4 ± 1.3	57.5%	②	5 times/week, ≥ 30 min/time	√			√	√	15
Engels et al ⁴³ , 2021	357	United States	14.2 ± 0.9	71.8%	①	≥ 5 days/week, accumulated MVPA ≥ 60 min/time	√		√			21

F% refers to the proportion of female in the overall respondents; N/A = Not Applicable; SOC = stage of change; POC = process of change; SEI = self-efficacy; DBL = decisional balance; PA = physical activity; MPA = moderate physical activity; VPA = vigorous physical activity; MVPA = moderate-to-vigorous physical activity; ① = Forced discrete measurement; ② = Progressive stage measurement.

Table II. Progressive stage measurement structure.

Item	If you answer...				
	No	No	Yes	Yes	Yes
(1) I am currently participating in physical activity	No	No	Yes	Yes	Yes
(2) I intend to be more physically activity in the next 6 months	No	Yes	—	—	—
(3) I am currently participating in regular physical activity	—	—	No	Yes	Yes
(4) I have been participating in regular physical activity for the past 6 months	—	—	—	No	Yes
Stage	PC	C	P	A	M

PC = Precontemplation; C = Contemplation; P = Preparation; A = Action; M = Maintenance.

SOC and consciousness raising, dramatic relief, self-reevaluation, environmental reevaluation in children and adolescents, and 4 studies^{28,30,39,40} were included to explore the relationship between SOC and social liberation in children and adolescents. In the comparative analysis of adjacent stages of the cognitive process, the included studies have great heterogeneity ($I^2 > 50\%$, $p < 0.1$), so the random effect model was used to test the combined effect. Results (Table III): The PC group was significantly lower than the C group in cognitive process ($p < 0.01$); the C group was significantly lower than the P group in consciousness raising and self-reevaluation ($p < 0.05$); the P group was significantly lower than the A group in consciousness raising, self-reevaluation, and environmental reevaluation ($p < 0.05$); the A group was significantly lower than the M group in consciousness raising ($p < 0.01$).

The relationship between the SOC and behavioral processes

In this meta-analysis, 5 studies^{28,30,34,39,40} were included to explore the relationship between the SOC and helping relationships, counterconditioning, reinforcement management, stimulus control in children and adolescents, and 4 studies^{28,30,39,40} were included to explore the relationship between SOC and self-liberation in children and adolescents. In the comparative analysis of adjacent stages of the behavioral process, the included studies have great heterogeneity ($I^2 > 50\%$, $p < 0.1$), so the random effect model was used to test the combined effect. Results (Table IV): The PC group was significantly lower than the C group in the behavioral process ($p < 0.01$); the C group was significantly lower than the P group in helping relationships, counter-conditioning, self-liberation, stimulus control ($p < 0.05$); the P

Table III. Meta-analysis of the relationship between the SOC and cognitive processes in children and adolescents.

Cognitive process	Stage comparison	Number of studies	Heterogeneity test			Main effects test		
			I^2	p	Z	p	SMD	95% CI
Consciousness raising	PC vs. C	5	98.9%	0.000	3.27	0.001	-0.714	(-1.141, -0.286)
	C vs. P	5	97.8%	0.000	1.34	0.181	-0.197	(-0.485, 0.091)
	P vs. A	5	97.2%	0.000	2.37	0.018	-0.308	(-0.562, -0.054)
	A vs. M	5	83.4%	0.000	4.04	0.000	-0.214	(-0.318, -0.110)
Dramatic relief	PC vs. C	5	98.5%	0.000	3.08	0.002	-0.548	(-0.898, -0.199)
	C vs. P	5	89.9%	0.000	2.71	0.007	-0.184	(-0.317, -0.051)
	P vs. A	5	98.3%	0.000	0.40	0.690	-0.066	(-0.393, 0.260)
	A vs. M	5	91.3%	0.000	0.04	0.967	-0.003	(-0.146, 0.140)
Self-reevaluation	PC vs. C	5	98.6%	0.000	3.22	0.001	-0.593	(-0.955, -0.232)
	C vs. P	5	95.7%	0.000	2.18	0.029	-0.226	(-0.430, -0.023)
	P vs. A	5	97.5%	0.000	2.44	0.015	-0.338	(-0.609, -0.067)
	A vs. M	5	93.3%	0.000	0.10	0.919	-0.008	(-0.172, 0.155)
Environmental reevaluation	PC vs. C	5	97.6%	0.000	3.49	0.000	-0.488	(-0.763, -0.214)
	C vs. P	5	91.3%	0.000	1.68	0.094	-0.123	(-0.266, 0.021)
	P vs. A	5	84.7%	0.000	4.46	0.000	-0.246	(-0.355, -0.138)
	A vs. M	5	91.4%	0.000	0.15	0.881	0.011	(-0.133, 0.155)
Social liberation	PC vs. C	4	98.1%	0.000	3.39	0.001	-0.606	(-0.957, -0.256)
	C vs. P	4	95.0%	0.000	1.24	0.214	-0.134	(-0.345, 0.077)
	P vs. A	4	94.7%	0.000	1.80	0.072	-0.188	(-0.393, 0.017)
	A vs. M	4	69.3%	0.021	2.06	0.093	-0.090	(-0.175, -0.005)

group was significantly lower than the A group in helping relationships, counter-conditioning, reinforcement management, stimulus control ($p < 0.05$); the A group was significantly lower than the M group in counter-conditioning, reinforcement management, self-liberation, stimulus control ($p < 0.05$).

The relationship between the SOC and SEI, DBL

In this meta-analysis, 13 studies^{27,29,30,32,33,35,37,39-41,43} were included to explore the relationship between SOC and SEI, and 10 studies^{27-30,32,33,37-42} were included to explore the relationship between SOC and DBL in children and adolescents. In the comparative analysis of adjacent stages of SEI and DBL, the included studies have great heterogeneity ($I^2 > 50\%$, $p < 0.1$), so the random effect model was used to test the combined effect. Results (Table V): from the P group to the M group, the SEI of the former stage was significantly lower than that of the latter stage ($p < 0.01$). For DBL, the PC group was significantly lower than the C group in pros ($p < 0.01$); the C group was significantly lower than the P group in pros ($p < 0.05$), and the C group was significantly higher than the C group in cons ($p < 0.01$); the P group

was significantly lower than the A group in cons ($p < 0.01$); the A group was significantly lower than the M group in pros ($p < 0.05$).

Validity Test for SOC of PA

Meta-analysis included 4 studies^{31,35,38,42}, 3 studies^{31,32,38}, 3 studies^{31,32,38} and 2 studies^{31,32} to respectively explore the relationship between SOC and total physical activity (TPA), vigorous physical activity (VPA), moderate physical activity (MPA), and lower physical activity (LPA) in children and adolescents. There was no heterogeneity in the comparison of the stage P and the stage A, the stage A and the stage M of LPA, so a fixed effect model was used to test the combined effect ($I^2 < 50\%$, $p > 0.1$). There was a large heterogeneity in the comparative analysis of the adjacent stages of the remaining physical activities, and the random effect model was used for the combined effect test ($I^2 > 50\%$, $p < 0.1$). Results (Table VI): The PC group was significantly lower than the C group in MPA ($p < 0.05$); the C group was significantly lower than the P group in TPA, VPA and MPA ($p < 0.01$); the P group was significantly lower than the A group in TPA and VPA ($p < 0.05$); the A group was significantly lower than the M group in TPA and VPA ($p < 0.01$).

Table IV. Meta-analysis of the relationship between the SOC and behavioral processes in children and adolescents.

Behavioral process	Stage comparison	Number of studies	Heterogeneity test			Main effects test		
			I^2	p	Z	p	SMD	95% CI
Helping relationships	PC vs. C	5	97.9%	0.000	2.64	0.008	-0.394	(-0.686, -0.101)
	C vs. P	5	94.6%	0.000	2.35	0.019	-0.220	(-0.402, -0.037)
	P vs. A	5	93.6%	0.000	2.72	0.007	-0.233	(-0.400, -0.065)
	A vs. M	5	93.7%	0.000	1.15	0.252	-0.098	(-0.266, 0.070)
Counter-conditioning	PC vs. C	5	97.9%	0.000	3.31	0.001	-0.504	(-0.804, -0.205)
	C vs. P	5	99.0%	0.000	2.40	0.016	-0.524	(-0.952, -0.096)
	P vs. A	5	97.8%	0.000	3.14	0.002	-0.464	(-0.754, -0.175)
	A vs. M	5	60.7%	0.000	7.49	0.000	-0.258	(-0.326, -0.191)
Reinforcement management	PC vs. C	5	97.5%	0.000	3.37	0.001	-0.462	(-0.731, -0.194)
	C vs. P	5	99.1%	0.000	1.73	0.084	-0.389	(-0.830, 0.052)
	P vs. A	5	98.0%	0.000	2.27	0.023	-0.353	(-0.659, -0.048)
	A vs. M	5	83.6%	0.000	2.55	0.011	-0.136	(-0.240, -0.031)
Self-liberation	PC vs. C	4	98.4%	0.000	4.49	0.000	-0.900	(-1.293, -0.507)
	C vs. P	4	97.8%	0.000	2.43	0.015	-0.400	(-0.723, -0.077)
	P vs. A	4	99.1%	0.000	1.75	0.080	-0.450	(-0.955, 0.054)
	A vs. M	4	79.6%	0.002	2.79	0.005	-0.149	(-0.253, -0.044)
Stimulus control	PC vs. C	5	95.4%	0.000	3.17	0.002	-0.320	(-0.518, -0.122)
	C vs. P	5	97.8%	0.000	2.34	0.019	-0.341	(-0.626, -0.055)
	P vs. A	5	97.0%	0.000	3.40	0.001	-0.428	(-0.674, -0.181)
	A vs. M	5	94.4%	0.000	2.00	0.045	-0.183	(-0.361, -0.004)

Table V. Meta-analysis of the relationship between the SOC and SEI, DBL in children and adolescents.

Outcomes	Stage comparison	Number of studies	Heterogeneity test			Main effects test		
			I ²	p	Z	p	SMD	95% CI
SEI	PC vs. C	13	98.1%	0.000	4.28	0.000	-0.386	(-0.563, -0.210)
	C vs. P	13	95.5%	0.000	5.69	0.000	-0.333	(-0.447, -0.218)
	P vs. A	13	97.4%	0.000	5.24	0.000	-0.404	(-0.555, -0.253)
	A vs. M	13	93.8%	0.000	9.87	0.000	-0.500	(-0.599, 0.070)
DBL-pros	PC vs. C	10	98.1%	0.000	7.23	0.000	-0.729	(-0.927, -0.532)
	C vs. P	10	93.7%	0.000	2.27	0.023	-0.124	(-0.230, -0.017)
	P vs. A	10	99.1%	0.000	1.56	0.118	-0.221	(-0.499, 0.056)
	A vs. M	10	97.0%	0.000	2.80	0.005	-0.218	(-0.370, -0.065)
DBL-cons	PC vs. C	10	99.2%	0.000	1.78	0.075	0.284	(-0.028, 0.597)
	C vs. P	10	94.5%	0.000	3.90	0.000	0.242	(0.120, 0.0364)
	P vs. A	10	99.3%	0.000	3.69	0.000	0.650	(0.305, 0.995)
	A vs. M	10	98.2%	0.000	1.30	0.194	0.142	(-0.072, 0.756)

Sources of Literature Heterogeneity

The results of the literature heterogeneity test showed that there was a high degree of heterogeneity among the included studies, so it is necessary to explore the source of heterogeneity for the study characteristics that caused the heterogeneity⁴⁶. In this study, the effect size of SEI was used as the dependent variable. Our study encodes the research characteristics such as publication year, sample size, country of subjects, age of subjects, proportion of females, stage algorithm, PA criteria, and literature quality, and sets them as independent variables for multivariate meta-regression analysis. The results of the multivariate

meta-regression analysis (Table VII) showed that the characteristics of the above study explained 11.1% of the sources of heterogeneity in the included studies (Adj-R² = 11.1%).

Publication Bias Test

The reliability of the meta-analysis results depends on whether the included studies are biased. This study used Egger’s linear regression to test for publication bias. Egger’s linear regression is a method to quantitatively test whether there is publication bias, which is used to compensate for the lack of subjective judgment of funnel chart⁴⁷. Egger’s linear regression model

Table VI. Meta-analysis of the relationship between SOC and PA in children and adolescents.

PA	Stage comparison	Number of studies	Heterogeneity test			Main effects test		
			I ²	p	Z	p	SMD	95% CI
TPA	PC vs. C	4	99.0%	0.000	1.73	0.084	-0.329	(-0.702, 0.044)
	C vs. P	4	99.7%	0.000	5.74	0.000	-2.036	(-2.731, -1.340)
	P vs. A	4	99.3%	0.000	2.00	0.046	-0.473	(-0.936, -0.009)
	A vs. M	4	97.5%	0.000	5.01	0.000	-0.626	(-0.871, -0.381)
VPA	PC vs. C	3	96.4%	0.000	1.10	0.270	-0.154	(-0.428, 0.120)
	C vs. P	3	98.4%	0.000	2.84	0.004	-0.598	(-1.011, -0.186)
	P vs. A	3	95.9%	0.000	2.96	0.003	-0.387	(-0.643, -0.130)
	A vs. M	3	88.7%	0.000	5.68	0.000	-0.452	(-0.608, -0.296)
MPA	PC vs. C	3	94.4%	0.000	2.48	0.013	-0.911	(-1.632, -0.191)
	C vs. P	3	98.0%	0.000	2.67	0.008	-0.502	(-0.870, -0.133)
	P vs. A	3	90.1%	0.000	1.51	0.131	-0.127	(-0.292, 0.038)
	A vs. M	3	98.2%	0.000	0.78	0.438	-0.152	(-0.536, 0.232)
LPA	PC vs. C	2	94.5%	0.000	0.74	0.460	0.150	(-0.247, 0.547)
	C vs. P	2	98.6%	0.000	1.47	0.143	-0.618	(-1.445, 0.208)
	P vs. A	2	0.0%	0.517	1.09	0.278	0.046	(-0.037, 0.128)
	A vs. M	2	0.0%	0.688	0.86	0.392	0.036	(-0.046, 0.118)

Table VII. Results of multivariate meta regression analysis.

Study characteristics	β	SE	t	p	95% CI
Publication year	-0.016	0.035	-0.47	0.664	(-0.114, 0.081)
Sample size	0.000	0.000	0.36	0.734	(-0.000, 0.000)
Country of subjects	0.073	0.082	0.89	0.423	(-0.155, 0.301)
Age of subjects	-0.290	0.163	-1.78	0.149	(-0.741, 0.162)
Proportion of females	0.330	0.465	0.71	0.517	(-0.961, 1.621)
Stage algorithm	-0.012	0.478	-0.03	0.981	(-1.339, 1.315)
PA criteria	0.190	0.181	1.05	0.353	(-0.312, 0.691)
Literature quality	-0.156	0.131	-1.19	0.299	(-0.520, 0.208)
Constant	38.968	72.570	0.54	0.620	(-162.518, 240.454)
Adj-R2			11.1%		

uses the effect size as the dependent variable and uses the accuracy of the effect estimator as the independent variable to construct a linear regression equation. The intercept of the regression equation is the offset. The closer it is to 0, the less likely there is publication bias⁴⁷. If $p > 0.05$ and the 95% CI contains 0, this indicates that there is no publication bias. In general, the publication bias test requires a certain number of included studies, which in principle should be more than 5⁴⁸. Therefore, our study conducted a publication bias test for SEI and DBL. The results (Figure 2) showed that there was no publication bias in the included studies.

Literature Sensitivity Analysis

The literature sensitivity analysis is an important method used in meta-analysis to evaluate the robustness and reliability of the combined results, which can assess whether the combined results are significantly changed by a certain study. There was no substantial change in the results of the combined effect test by excluding a study one by one, so the included studies did not have literature sensitivity issues.

Discussion

Factors of Change in PA Behavior in Children and Adolescents

The POC is a strategy and method to help individuals progress in stages and is an important basis for formulating intervention strategies⁴⁹. The results of the meta-analysis show that cognitive and behavioral processes play different roles in the transition between adjacent stages of PA in children and adolescents. This result denies the research hypothesis of Dishman et al⁵⁰ that cognitive processes play a major role in the promotion of behavioral intentions, and the behavioral process plays an important role in the promotion of the actual action process¹². At the same time, this result further supports the research results of Marshall et al⁵¹, that is, when individuals change their behavior, they will choose cognitive, emotional, and behavioral strategies to help themselves achieve behavior change. Fang²⁸, Nigg and Courneya³⁰ and Sas-Nowosielski³⁹ found that 10 change processes were all predictors of PA behavior changes in children and adolescents. However, Bucksch

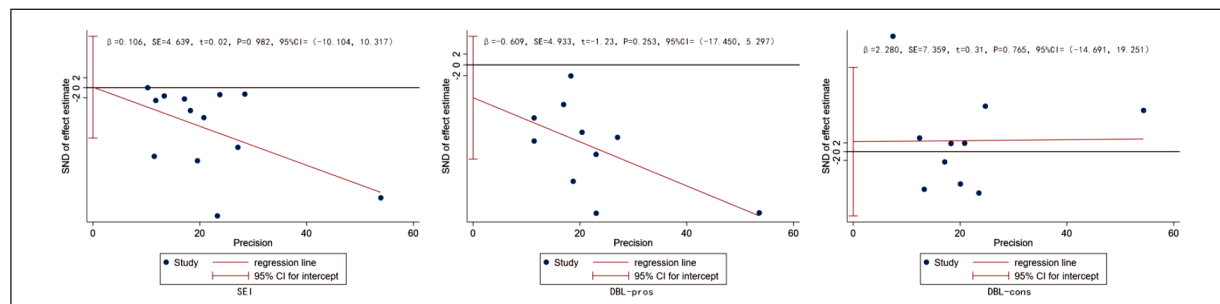


Figure 2. Egger's linear regression bias test results.

et al⁴⁰ believed that social liberation, helping relationships, and self-liberation could not effectively distinguish the PA stages of German adolescents; Hwang and Kim³⁴ showed that there was no stage difference between dramatic relief and self-reevaluation. On the one hand, the regular PA criteria defined by studies such as Bucksch et al⁴⁰ is different from the above studies, and has increased in frequency, time, and type of PA. On the other hand, the revised POC scale has lost some dimensions. For example, the revised scale of Hwang and Kim³⁴ is not suitable for Korean adolescents in terms of social liberation and self-liberation. However, the results of the meta-analysis showed that the 10 dimensions of the POC were significant factors for the change in PA behavior in children and adolescents. More cognitive processes peaked in stage A, while more behavioral processes peaked in stage M. As the stages increase, the role played by the cognitive processes gradually decreases, while behavioral processes play an important role in all stages. There are obvious differences in cognition, emotion, and environmental perception in the SOC, that is, the role of the POC in each stage is not consistent⁵¹. Our study demonstrated that 10 POCs facilitated the transition from the PC stage to the C stage during the transition from PA to children and adolescents. Except for stimulus control, the effect size of the 9 POCs was the largest in the transition from PC stage to C stage (SMD = -0.900 – -0.394), among which consciousness raising, dramatic relief, self-reevaluation, counterconditioning, self-liberation reached medium to large effect. 7 POCs facilitated the transition from stage P to stage A. Except for stimulus control and counterconditioning, the effect sizes of the 5 POCs from stage P to stage A were large (SMD = -0.428 – -0.233), and all were small. During the stage transition, the effect size of self-liberation was the largest (SMD = -0.900) from the PC stage to the C stage, while the effect size of dramatic relief was the lowest (SMD = -0.003) from stage A to stage M. The above shows that PA in children and adolescents requires greater effort in cognitive, emotional, and behavioral strategies from inactive intention to active intention and from preparation to action.

Although the SEI includes environmental incentives and self-confidence, more studies explore only the degree of self-confidence of individuals participating in PA. Meta-analysis results show that the self-confidence increases

with the stage, which is consistent with the hypothesis of Dishman et al⁵⁰ and Buxton et al⁵². However, the development of SEI is not linear, but shows obvious stage characteristics, that is, the improvement of SEI in the transition process of adjacent stages is not the same. In the transition from stage A to stage M, the effect size was the largest (SMD = -0.500), reaching a medium effect; while in the transition from stage C to stage P, the effect size was the smallest (SMD = -0.333). This finding modifies the assertion of an earlier narrative review⁵³ about the linear development of SEI. This suggests that we should pay special attention to the improvement of post-action SEI when performing stage-matched interventions, to promote the maintenance of PA in children and adolescents.

DBL including pros and cons, together with SEI, can explain more than 40% of the variation in PA behavior changes in children and adolescents^{27,33}. The results of the meta-analysis show that the pros of children and adolescents show an upward trend, and the cons show a downward trend with the increase of stages. This upward and downward trend shows obvious stage characteristics, that is, the pros and cons of children and adolescents have the largest effect size from the PC stage to the C stage (SMD = -0.729) and from stage P to stage A (SMD = 0.650), respectively. While the pros were in stage P to stage A, the effects of the cons in stage PC to stage C and stage A to stage M were not significant. The upward and downward trend of pros and cons will inevitably lead to the intersection of DBL, and this point has also been widely explored by researchers⁵⁴. The results of this study show that the intersection of pros and cons is around the stage P. This suggests that when we carry out phase-matched interventions, we should aim at improving the subjective benefits of PA in the early stage of the intervention; in the middle of the intervention, we should focus on improving the subjective benefits and reducing the perception of obstacles; in the later stage of the intervention, we should aim at reducing the perception of obstacles in PA.

Validity of PA Tests for the SOC

The SOC is a complex structure that contains intention, behavior, and temporal components, and researchers often use self-reported or objectively measured PA to assess the effectiveness of the stage of PA^{55,56}. Hellsten et al⁵⁷ believed that there were stage differences in

the increasing trend of PA and put forward the hypothesis of “PC/C<P<A/M” of PA stages. This hypothesis points to the flaw in using PA to test the validity of SOC, that is the inability of PA to effectively discriminate between PC stage and C stage, and stage A stage and stage M. However, the results of the meta-analysis showed that PA did not fully support this hypothesis. In addition, TPA and VPA can effectively distinguish other stages, except the PC stage and C stage; MPA can distinguish the PC stage and stage C, as well as the C and P stage; LPA does not appear to have a high degree of discrimination for SOC. This study further supports the findings of Lee et al³¹ and Berry et al³². The results show that VPA has the highest discrimination for SOC, followed by MPA, and LPA does not have stage difference. In summary, with increasing PA intensity, the discrimination of SOC also improved, but PA still could not fully distinguish each stage. Therefore, we suggest that the SOC of different judgment criteria can be compared by comprehensive behavioral data, exercise willingness, exercise habits, etc. We can test the concept and validity of SOC based on the assumptions that behavioral data distinguish PA from inactivity, exercise intention distinguishes the PC stage from the C stage, and exercise habits distinguish between stage A and stage M.

Conclusions

This study is the first to use meta-analysis to test the effectiveness of TTM in the application of PA behavior changes in children and adolescents and the effectiveness of PA identification of SOC. First, we have sufficient evidence to show that changes in PA behavior of children and adolescents are associated with POC, SEI, and DBL, and the POC, SEI, and DBL have obvious stage characteristics. Second, in general, with the increase of the intensity of PA, the discrimination of SOC also improved, but PA still could not fully distinguish each stage. We recommend follow-up studies to compare the SOC of different criteria by integrating behavioral data, exercise willingness, and exercise habits. However, this study has the following limitations: (1) Research in this field is relatively scarce and most of them are cross-sectional studies, and the evidence support provided by cross-sectional studies is relatively weak. It is recommended that more studies use longitudinal surveys or experimental interven-

tions to test the rationality of TTM. (2) There are differences in measurement tools among the included studies. The reliability of these measurement tools has not been effectively verified, so standardized measurement tools are urgently needed, but at the same time, multiple measurement methods for the same variable can provide evidence of construct validity.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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Authors' Contributions

Y. W. Lu: drafted the article, analyzed and interpreted the data. P. Shi: designed the research. J. Y. Sun and Z. Y. Zhang searched for relevant articles and made article selections. All authors participated the intellectual content of the manuscript.

Ethics Approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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