Original Article

Association of screen time-based sedentary behavior and the risk of depression in children and adolescents: Dose-response meta-analysis

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ABSTRACT

Purpose: We aimed to find the association between screen time (ST)-based sedentary behavior and depression in children and adolescents.

Methods: PubMed, Embase, and Web of science database were searched to find eligible studies until April 25, 2021. Data extraction was conducted by two investigators independently, followed by quality assessment for included studies. Odd ration (OR) and 95% confidence intervals (CI) were regarded as effect size index. Heterogeneity test was conducted using Cochran' s Q test and I^2 test. Least squares trend estimation method was used for dose-response meta-analysis. All statistical analyses were conducted using Stata12.0 software.

Results: Totally 22 articles containing 197,673 cases were included. The pooled results displayed that there was a significant positive correlation between ST and depression [OR (95%CI) = 1.24 (1.11, 1.38), P < 0.001]. Similar results were observed for watching television (TV), computer use (CU), computer game (CG)/video game (VG) and internet use (IU)/mobile phone (MP) time. Dose-response meta-analysis showed that take 1 hour/day as control, the risk of depression went down and then went up as sedentary time increased for ST (P > 0.05). The risk of depression was significantly increased when TV time beyond 4.5 hours/day (P < 0.05), or CU time beyond 0.5 hours/day (P < 0.05), or CG/VG time beyond 2 hours/day (P < 0.05), or IU/MP time beyond 0.5 hours/day (P < 0.05).

Conclusions: ST-based sedentary behavior was associated with the risk of depression in a non-linear dose–response manner for children and adolescents.

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Keywords: Depression; screen time; children and adolescents; dose-response meta-analysis

Introduction

Depression is one of the most common mental health disorders in the world [1]. Adolescence is a time when it is easy to suffer from depression [2]. Depression increases the risk of suicide, poor health, poor social well-being, and unhealthy lifestyle behaviors in adolescents and young people [3,4]. Worldwide, the prevalence of depression among adolescents is approximately 11%, and the rate increases with age [5,6]. In consideration of the prevalence and burden of depression during adolescence, it is crucial to understand the risk factor of this disease in order to find effective interventions for depression.

It is reported that depressive symptoms can be influenced by lifestyle factors such as an excessive amount of screen time (ST) [7]. ST including watching television (TV), video game (VG), internet use (IU), computer use (CU), computer game (CG), and mobile phone (MP), is becoming a major part of young children's and teenagers' daily lives in the modern world [8]. Meanwhile, ST-based sedentary behavior has been reported to be associated with depression [9,10]. Excessive screen-based activities had been identified as potential risk factors for mental health problems [11-13]. Some cross-sectional studies reported the association of ST with depressive symptoms in young people [14,15]. A previous meta-analysis explored the association between ST-based sedentary behavior and depression in children and adolescents, which revealed that ST is associated with depression risk in a non-linear dose–response manner in children and adolescents [16]. However, in this previous meta-analysis, the number of studies included was small, and part of the content used estimation methods to obtain OR (95%CI) for the association of ST-based sedentary behavior with the risk of depression, which might lead to inaccurate results. In addition, the results of some newly published studies were inconsistent with the results of this meta-analysis. For instance, Twenge et al. [17] indicated that not all ST was created equal and associations between screen media use and mental health varied considerably depending on the type of activity and gender. Mridha et al. [18] revealed that the prevalence was higher among girls in most sociodemographic, lifestyle and anthropometric strata. Therefore, a more comprehensive meta-analysis is needed to obtain consistent results of the association between ST-based sedentary behavior and depression in children and adolescents.

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Meta-analysis is a useful and important tool for combining information from relevant researches [19]. Currently, dose-response meta-analysis was performed to find the association between ST-based sedentary behavior and depression in children and adolescents. Studies meeting the inclusion criteria were searched from the database of PubMed, Embase and Web of science. Additionally, subgroup analysis and dose-response meta-analysis concerning ST, TV, CU, CG/VG, and IU/MP were conducted. Our present meta-analysis may provide helpful instructions for the mental health of children and adolescents.

Methods

This meta-analysis was performed based on PRISMA guideline.

Search strategy

The database of PubMed (https://www.ncbi.nlm.nih.gov/pubmed/), Embase (https://www.elsevier.com/solutions/embase-biomedical-research) and Web of science were searched without language restriction up to April 25, 2021. The following keywords were applied in the search: "adolescent", "adolescence", "teenager", "students", "child", "children", "watching television", "video game", "computer use", "internet use", "screen use", "sedentary behavior", "sitting time", "screen time", "depression", "depressive disorder", and "mental health". The specific search steps for the databases of PubMed, Embase, and Web of science were presented in supplementary Table 1. In addition, manual searches on paper-based literature were conducted; meanwhile, relevant reviews as well as references of included articles were screened to obtain more studies that can be used for the present meta-analysis.

Study selection

Studies were included if the following criteria were met: (1) the research object was children and adolescents under the age of 20; (2) the ST-based sedentary behavior was reported and the research object was grouped according to sedentary time; (3) the study type was observational cross-sectional, case-control or longitudinal study design; (4) the outcome reported the association between ST and the risk of depression, and OR/RR (95%CI) was reported or could be converted based on variables in the table.

The exclusion criteria were defined as follows: (1) summary, conference abstracts, reviews and other non-authoritative research; (2) the outcomes were correlation coefficient of sedentary time and depression, and studies that reported the comparison of sedentary time between depression group and control group were excluded; (3) for repeated publications or the same data used in multiple articles, only the one with the most complete research information were included, and the rest were excluded; (4) non-ST-based sedentary behavior (such as reading books, newspapers, and driving).

Data extraction and quality assessment

The literature search was completed by two investigators independently. The following information of eligible literature were extracted: the first author, publication year, study type, survey area and time, characteristics of participants (sample size, age, and gender, etc.), type of ST, depression measurement tool, confounding factors and study outcomes. Disagreements were resolved by discussions.

The methodological quality of the observational studies was evaluated with reference to the bias assessment tool used by Liu et al. [16]. The tool had six evaluation items and full score was eight points. One point was the appropriate screening of the participants. Two points were used to measure depression and ST, respectively. One point was the appropriate approach to address any design-specific problems (recall bias, interviewer bias for cross-sectional studies and biased loss to follow-up for longitudinal studies). One point was the method of controlling confounding factor, and one point was the appropriate statistical method.

Statistical analysis

Odd ration (OR) and 95% confidence intervals (CI) were regarded as effect size index for the association between ST and the risk of depression. Heterogeneity test was conducted using Cochran' s Q test and I^2 test. If $P < 0.05$ and/or $I^2 > 50\%$, implying that there was significant heterogeneity between studies, then random effects model was applied to the meta-analysis. If $P \geq 0.05$ and $I^2 \leq 50\%$, implying that no significant heterogeneity was found between studies, then fixed effects model was applied. The effects of region, study type, gender, and confounding factors on heterogeneity and pooled results were evaluated by subgroup analysis. Funnel plot was applied to assess the significant publication bias. If there was significant publication bias, the stability of the results was evaluated by trim and fill method in sensitivity analysis.

Studies were divided into at least 3 dose-response groups (such as 0-1, 1-3, >3 hours/day) based on the length of ST. Studies were included in dose-response meta-analysis if the following criteria were met: (1) OR/RR (95%CI) of each dose-response group was reported. (2) sample size or person-years and the number of people with depression were reported for each group. Least squares trend estimation method developed by Sander et al. [20] and Orsini et al. [21] were used for this dose-response meta-analysis. All statistical analyses were conducted using Stata12.0 software (Stata Corp, College Station, TX, USA).

Results

Result of study selection

The flow chart of study selection was summarized in Figure 1. Firstly, 5508 (PubMed: 1372; Embase: 2099; Web of Science: 2037) eligible articles were obtained through database searching. After removing duplication, 3840 studies were obtained. Among them, 3793 articles were excluded after screening abstracts and titles. After that, 25 studies were removed through reading the full text. In addition, no eligible studies were found by manual search. Finally, 22 studies [15,17,18,22-40] were included in the present meta-analysis.

Characteristics of the study and quality assessment

As presented in Table 1, 22 studies containing 20 cross-sectional study (CSS) and 2 prospective cohort study (PCS) were included in this meta-analysis. The publication year was 2009-2021. Six studies were conducted in China, three in Australia, three in USA, two in Korea, one in Canada, one in Brazil, one in Switzerland, one in Portugal, one in Denmark, one in Iceland, one in Bangladesh, and one in UK. The sample size ranged from 244 to 75,066 cases, with a total of 197,673 cases (male: 101649; female: 95994). The cases were aged between 7 and 19 years. These studies reported the association of ST and the risk of depression, or the association of a specific sedentary behavior (such as TV, VG, internet use IU, CU, CG, MP) and the risk of depression. The depression measurement tool included Depressive Tendencies Scale (DTS), Depression Self-rating Scale for Children (DSRSC), the Center for Epidemiologic Studies Depression Scale (CES-D), Composite International Diagnostic Interview (CIDI) short form, BDI-II, Major Depression Inventory (MDI) scale, short moods and feelings questionnaire (SMFQ), the Diagnostic and Statistical Manual of Mental Disorders Version IV (DISC-IV), The Children's Depression Inventory (CDI), Subscales of the Symptom Checklist 90 (SCL-90), Self-reported, Doctor or health professional, The nine-item adolescent Patient

Table 1. Characteristics of the included studies

Study	Area, Survey time	Type of study	n, M/F	Age, years	Screen-time (hrs/day): style; categories	Depression measure; cutoff	Adjustment for confounders
Bélanger et al. [24]	Switzerland, 2002	CSS	7211, 3905/3306	17.91±2.11	CU; 0, 0-<1, 1-≤2, >2	DTS. Cutoff: NR	Age; academic track; socioeconomic status; chronic condition; PA
Cao et al. [25]	China, 2010	CSS	5003, 2606/2397	13.2±1.0	ST (TV/CU); <2, >2	DSRSC. Cutoff : 15	Gender, grade, family type, perceived socioeconomic status, BMI, fruit and vegetable intake, and fizzy drinks intake
Cao et al. [26]	China, 2018	CSS	4178, 1946/2232	14.25±1.77	ST (TV/VG/CU/MP); <2, >2	CES-D. Cutoff: 16	Gender, age, living in school dormitory accommodation, school type and perceived socioeconomic status
Casiano[16]	Canada, 2000-2001	CSS	9137, 4544/4593	12-19	TV, VG, CU; 0, <1/7, <1/3, 0.4-0.7, 0.8-1.4, 1.5-2, 2-3, ≥3	CIDI short form. Cutoff: 0.90	Household income; gender
da Costa, et al. [27]	Brazil, 2019	CSS	610, 295/315	16.33±1.4	TV, VG, MP; <2, 2-4, ≥4	CES-D. Cutoff: 20	Sex, age, weight status, and socioeconomic status
Godinho, et al. [28]	Portugal, 2003-2004	CSS	1680, 796/884	13	ST (≤2, 2-3, >3); TV (≤1, 1-2, >2); CU (≤2, >2)	BDI-II. Cutoff: 13	Living with both parents, Parents' age, Type of school, Repeated school year, Sleep duration, Ever smoke, Frequency of PA, BMI
Grøntved et al. [29]	Denmark, 2009-2010	PCS	435, 203/232	15.6±0.4	ST, TV (0-1, 1-3, >3); CU (0-1, 1-3)	MDI scale. Cutoff: 20	Age, BMI and CRF, follow-up time, sex, parental education level, parentalmarital status, smoking status, and alcohol intake in adolescence
Hoare et al. [30]	Australia, 2012	CSS	800, 360/440	13.1±0.6	ST (TV/VG/CU); ≤2, >2	SMFQ. Cutoff: 10.	Age, PA, weight status, fruit and vegetable, sweet drink, takeaway food consumption over a month period, parents' level of education, and school
Hoare, et al. [31]	Australia, 2013-2014	CSS	2967, 1530/1437	14.6±2.0	IU; ≤2, 2-6, ≥7	DISC-IV. Cutoff: NR	Age, relative level of socio-economic disadvantage and BMI
Hong et al. [32]	China, 2004	CSS	2444, 1180/1264	13.85±1.04	TV; Low, middle, high	CDI. Cut-off: 20	Age; gender; school grade; BMI; study time; sleep time; smoking; alcohol; unintentional injuries; parents' education, parents' job; family structure
Hrafnkelsdottir et al. [33]	Iceland, 2015	CSS	244, 100/144	15.8±0.3	ST (CG,TV, IU, CU) <5.3, ≥5.3	SCL-90. Cut-off: 30	Sex, body fat percentage and maternal education
Kim et al. [34]	Korea, 2009	CSS	75066, 39612/35454	12-18	CU; 0, 0-<1, 1-≤2, >2	Self-reported	Age, residing region, type of school, subjective academic performance status, subjective economic status, presence of parents, family lives together and sedentary behavior in weeks and weekend
Kremer et al. [35]	Australia, 2006	CSS	8029, 3852/4177	11.5±0.8	ST (TV/VG/CU): <2, ≥2	SMFQ. Cut-off: ≥8	Location and area- socioeconomic status
Lee et al. [36]	USA, 2015	CSS	15624, 8015/7609	High school students	VG; 0, <1, 1, 2, 3, 4, ≥5	Self-reported	Crude
Leung et al. [37]	USA, 2018	CSS	10794, 5710/5084	13-17	TV; <1, 1, 2, 3, ≥4	Doctor or health professional	Sex, age, poverty level, insurance type, parent education, language spoken at home, race/ethnicity, household generation, family structure, comorbid conditions, and emotional/behavior medications
Lim et al. [38]	Korea, 2008	CSS	920, 633/287	15-17	IU; 0-1, 1-3, >3	CES-D. Cutoff: 24	Sex, age, PA, BMI, Perception on body image, Figure satisfaction
Liu et al. [39]	China, 2015	CSS	11831, 5813/6018	15.0±1.5	MP; <1, 1-2, ≥2 (weekday)/<2, 2-<4, 4-<5, ≥5 (weekend)	CES-D. Cut-off:>90th percentile	Age, gender, chronic disease, smoking, alcohol use, school, family factors, weekday sleep duration, and insomnia
Mridha et al. [18]	Bangladesh, 2018-2019	CSS	9569, 4761/4808	10-19	TV; 0, 0-<1, 1-≤2, >2	PHQ-9. Cut-off: ≥5	Age, residence, educational status, maternal/paternal education and occupation, religion, household size, household member, tobacco use, Fruits and vegetables intake, Processed food intake, Consumption of fortified oil, Consumption of iodised salt, PA, Weight.
Primack et al. [22]	USA, 1994-2002	PCS	4142, 2145/1967	Grade 7-12	TV, CG; hours per day	CES-D; Cut-off: 24 (F), 22 (M).	Baseline CES-D score; age; gender; race/ethnicity; socioeconomic status; ever married; educational achievement of at least graduation from high school
Twenge et al. [17]	UK, 2015	CSS	11427, 5720/5707	13.77±0.45	TV, CG, IU; <1, 1-<2, 2-<5, ≥5	SMFQ. Cut-off: 12.	Age, family income, natural father present, ethnicity, the age the primary caregiver left formal education, primary caregiver's employment, number of siblings in household, longstanding illness, and the primary caregiver's vocabulary word score
Wang et al. [23]	China, 2017	CSS	1062, 576/486	15.38±1.74	ST (TV/VG/CU); ≤2, >2	SDS. Cutoff: 0.6	Grade, health status, family economic situation
Xu et al. [40]	China, 2017-2018	CSS	14500, 7347/7153	14.9±1.8	ST (TV/CU/MP); 0, <1, 1-2, 2-3, 3-4, 4-5, >5	CDI. Cut-off: 19.	Age, Grade, Residence, The only child in the family, Boarding school, Father/mother's education level, Self-perceived socioeconomic status, The number of close friend

NR: not reported; CSS: cross-sectional study; PCS: prospective cohort study; ST: screen time; VG: video game; TV: television viewing; IU: internet use; CU: computer use; CG: computer game; MP: mobile phone; F: female; M: male; BM: body mass index; CRF: cardiorespiratory fitness; PA: Physical activity.
DSRSC: Depression Self-rating Scale for Children; CES-D: the Center for Epidemiologic Studies Depression Scale; CIDI: Composite International Diagnostic Interview; MDI: Major Depression Inventory; SMFQ: moods and feelings questionnaire; DTS: Depressive Tendencies Scale; DISC-IV: the Diagnostic and Statistical Manual of Mental Disorders Version IV; SCL-90: Subscales of the Symptom Checklist 90; PHQ-9: The nine-item adolescent Patient Health Questionnaire; SDS: Self-rating depressive scale; CDI: The Children's Depression Inventory.

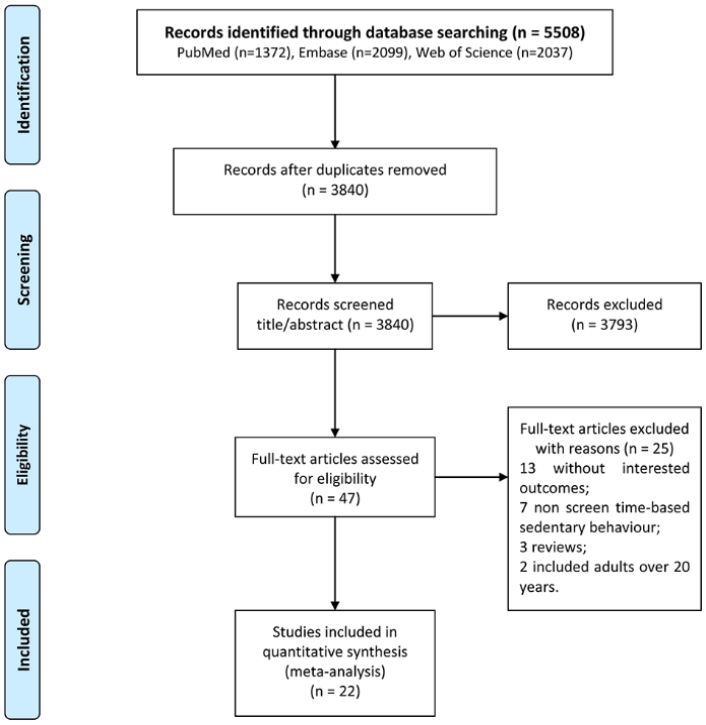

Figure 1. The flow chart of study selection.

Table 2. Quality assessment of the included studies

Study	Type of study	Source of population	Measurement for screen time	Measurement for depression	Methods to control confounding	Deal with any design-specific issues#	Appropriate statistical methods (excluding control of confounding)	Quality score
Bélanger et al. [24]	CSS	1	1	1	0	0	1	4
Cao et al. [25]	CSS	1	1	1	1	0	1	5
Cao et al. [26]	CSS	1	1	1	0	0	1	4
Casiano [15]	CSS	1	1	1	0	1	1	5
da Costa, et al. [27]	CSS	0	1	1	1	0	1	4
Godinho, et al. [28]	CSS	0	1	1	1	0	1	4
Grøntved et al. [29]	PCS	1	1	1	1	0	1	5
Hoare et al. [30]	CSS	0	1	1	1	0	1	4
Hoare et al. [31]	CSS	0	1	1	1	0	1	4
Hong et al. [32]	CSS	1	1	1	0	1	1	5
Hrafnkelsdottir et al. [33]	CSS	1	1	1	0	0	1	4
Kim et al. [34]	CSS	1	1	0	1	0	1	4
Kremer et al. [35]	CSS	0	1	1	1	0	1	4
Lee et al. [36]	CSS	0	1	1	0	0	1	3
Leung et al. [37]	CSS	0	1	1	1	0	1	4
Lim et al. [38]	CSS	1	1	1	0	0	1	4
Liu et al. [39]	CSS	1	1	1	1	0	1	5
Mridha et al. [18]	CSS	1	1	1	1	0	1	5
Primack et al. [22]	PCS	1	1	1	1	1	1	6
Twenge et al. [17]	CSS	1	1	1	1	0	1	5
Wang et al. [23]	CSS	0	1	1	0	1	1	4
Xu et al. [40]	CSS	1	1	1	0	0	1	4

CSS: cross-sectional study; PCS: prospective cohort study. #: appropriate methods outlined to deal with any design-specific issues including: recall bias: interviewer bias for cross-sectional studies; and biased loss to follow-up for longitudinal studies

Health Questionnaire (PHQ-9), and Self-rating depressive scale (SDS). Except for the study of Lee et al. (37), some confounders were adjusted in other studies.

The results of quality assessment were shown in Table 2. Among the included studies, except for the score of Lee et al. [37] was 3, the score of the other studies were 4-6. Overall, the methodological quality of the included studies was moderate.

Results of meta-analysis

The study was divided into ST group, TV group, CU group, CG/VG group, and IU/MP group based on the type of sedentary behavior. The association between sedentary time and risk of depression was assessed in each group separately.

As shown in Figure 2A, nine articles (11 sets of data) reported the association between ST and depression, and significant heterogeneity was detected (I^2 = 72.4%, P < 0.001). The pooled results of random effects model displayed that there was a significant positive correlation between ST and depression [OR (95%CI) = 1.24 (1.11, 1.38), P < 0.001]. Nine articles (12 sets of data), five articles (eight sets of data), five articles (seven sets of data), and five articles (seven sets of data) reported the association of TV (Figure 2B), CU (Figure 2C), CG/VG (Figure 2D), as well as IU/MP (Figure 2E) and depression, respectively. Significant heterogeneity (I^2 > 50%, P < 0.05) was found for TV group, CU group, and CG/VG group, but no significant heterogeneity (I^2 = 36.9%, P = 0.147) for IU/MP group. The pooled results of TV group [OR (95%CI) = 1.38 (1.16, 1.64), P < 0.001], CU group [OR (95%CI) = 1.41 (1.14, 1.74), P = 0.002], CG/VG group [OR (95%CI) = 1.44 (1.02, 2.05), P = 0.038], and IU/MP group [OR (95%CI) = 1.90 (1.62, 2.21), P < 0.001] revealed that sedentary time of TV, CU, CG/VG, and IU/MP was positively correlated with the risk of depression for children and adolescents.

Subgroup analysis

Results of subgroup analysis were presented in Table 3. For ST group, TV group, and CG/VG group, area, study design, gender, and multivariate analysis were not significant sources of heterogeneity. In subgroup analysis of ST, except the pooled results of European, PCS, Female, and munivariate analysis were not statistically significant (P > 0.05), the results of other subgroups were consistent with the total pooled results. In subgroup analysis of TV, only the pooled results of Asian, CSS, male, and multivariate analysis were statistically significant (P < 0.05). In subgroup analysis of CG/VG, the pooled results of American, PCS, mixed gender, and multivariate analysis were not statistically significant (P > 0.05). For CU group, gender was the significant sources of heterogeneity. After grouping, there was no significant statistical heterogeneity for female subgroup and male group (I^2 = 0%, P > 0.05). Except the pooled results of American, PCS, and mixed gender were not statistically significant (P > 0.05), the results of other subgroups were consistent with the total pooled results. For IU/MP group, the pooled results of all subgroups were statistically significant (P < 0.05).

Dose-response meta-analysis

For ST, take 1 hour/day as the control, the risk of depression went down and then went up as sedentary time increased, but the difference was not statistically significant (P > 0.05, Figure 3A). For TV time, the risk of depression was significantly reduced in 1.5 hour/day compared with that in 0.5 hour/day [OR (95%CI) = 0.86 (0.75, 0.99), P = 0.033]. However, as the sedentary time increased, the risk of depression increased. The risk of depression was significantly increased when TV time beyond 4.5 hours/day (P < 0.05, Figure 3B). For CU time, the association between sedentary time and the risk of depression appeared in a "V" shape. Take 0.5 hour/day as the control, the risk of depression significantly increased as sedentary time decreased or increased (P < 0.05, Figure 3C). For CG/VG time, teenagers who played games ≥ 2 hour/days had an evidently higher risk of depression than those who did not (P < 0.05, Figure 3D). For IU/MP time, take 0.5 hour/day as the control, with the increase of sedentary time, the risk of depression increased significantly (P < 0.05, Figure 3E).

Publication bias and sensitivity analysis

Results of Egger's test for ST, TV, CU, CG/VG, and IU/MP were as follows: P = 0.021 (ST), P = 0.028 (TV), P = 0.033 (CU), P = 0.407 (CG/VG), and P = 0.609 (IU/MP). There was significant publication bias among the included studies of ST, TV, and CU, and thus the stability of the results was evaluated by trim and fill method for these three indicators. After using trim and fill method, the pooled results of ST were OR (95%CI) = 1.21 (1.08, 1.36), P = 0.001, and the pooled results of TV was OR (95%CI) = 1.36 (1.14, 1.61), P = 0.001. Meanwhile, there was no change for the pooled results of CU. Obviously, the results of sensitivity analysis revealed that there was a significant positive correlation between sedentary time and depression, and the pooled results were stable.

Discussion and conclusion

In the present meta-analysis, we evaluated the association of ST-based sedentary behavior with the risk of depression in children and adolescents. The results of meta-analysis showed that sedentary time of TV, CU, CG/VG, and IU/MP was positively correlated with the risk of depression for children and adolescents. The results of some previous studies were in line with our present results that sedentary time of TV, CU, CG/VG, and IU/MP was positively correlated with the risk of depression for children and adolescents. For instance, Cao et al. [26] indicated that compared with high and active sleep duration groups, depression symptoms were significantly higher in the high ST (including TV, VG, CU and MP) and low physical activity-low sleep duration groups by studying 4178 adolescent students. Researches from 10,907 adolescents aged 13-17 by Leung et al. [37] revealed that adolescents who used more than four hours of ST (including TV or videos and electronic devices) a day had higher rates of depression (OR = 2.23, 95% CI: 1.27-3.91) and anxiety (OR = 1.85, 95% CI: 1.26-2.72) than those who did not use ST. The possible reasons may be as follows: Excess ST can lead to disengagement from interpersonal relationships, while media content can shape people's emotions and behavior, leading to negative comparisons between oneself and others, which in turn can lead to depressive symptoms [41,42]. Portable devices such as CG/VG and IU/MP are more likely to interfere with face-to-face interactions and sleep, therefore may be more relevant to mental health [43,44].

Further dose-response meta-analysis indicated that: for ST, take 1 hour/day as the control, the risk of depression went down and then went up as sedentary time increased (P > 0.05). There was a continuously decreasing risk of depression with increasing TV time in the range of 0.5 hours/day to 1.5 hours/day (P = 0.033). The risk of depression was significantly increased when TV time beyond 4.5 hours/day (P < 0.05). The risk of depression was decreased with increasing CU time in the range of 0 hours/day to 0.5 hours/day, and inversely, the risk of depression increased with increasing CU time when CU time beyond 0.5 hours/day (P < 0.05). Compared with teenagers who had no CG/VG, the risk of depression increased with increasing CG/VG time when CG/VG time beyond 2 hours/day (P < 0.05). The risk of depression increased with increasing IU/MP time beyond 0.5 hours/day (P < 0.05). On the one hand, the risk of depression was significantly increased when TV time beyond 4.5 hours/day, or CU time beyond 0.5 hours/day, or CG/VG time beyond 2 hours/day, or IU/MP time beyond 0.5 hours/day, which

Table 3. Outcomes of the subgroup analysis.

Model	No. of studies	Heterogeneity test		Effect size	
		I^2 (%)	P_H	OR (95% CI)	P value
ST	11	72.4	<0.001	1.24 (1.11: 1.38)	<0.001
Area					
Asian	4	87.7	<0.001	1.28 (1.05: 1.56)	0.013
Australia	3	0	0.636	1.15 (1.06: 1.24)	0.001
European	4	67.2	0.027	1.71 (0.91: 3.22)	0.096
Study design					
CSS	10	73.0	<0.001	1.23 (1.10: 1.37)	<0.001
PCS	1	NA	NA	3.46 (0.96: 12.47)	0.058
Gender					
Mixed	7	81.8	<0.001	1.34 (1.11: 1.63)	0.03
Female	2	0	0.344	1.11 (1.01: 1.22)	0.26
Male	2	0	0.466	1.24 (1.07: 1.43)	0.05
Multivariate analysis					
Yes	10	74.6	<0.001	1.26 (1.13: 1.41)	<0.001
No	1	NA	NA	0.91 (0.59: 1.39)	0.656
TV	12	87.5	<0.001	1.38 (1.16: 1.64)	<0.001
Area					
Asian	3	70.3	0.035	1.72 (1.31: 2.25)	<0.001
American	4	82.2	0.001	1.12 (0.94: 1.34)	0.195
European	5	58.3	0.048	1.30 (0.97: 1.74)	0.074
Study design					
CSS	10	89.0	<0.001	1.40 (1.10: 1.79)	0.006
PCS	2	78.2	0.032	1.86 (0.49: 7.07)	0.360
Gender					
Mixed	6	78.9	<0.001	1.19 (1.00: 1.41)	0.050
Female	3	85.8	0.001	1.37 (0.92: 2.05)	0.122
Male	3	41.7	0.180	1.61 (1.23: 2.11)	0.001
Multivariate analysis					
Yes	11	88.3	<0.001	1.44 (1.20: 1.72)	<0.001
No	1	NA	NA	0.78 (0.49: 1.23)	0.283
CU	8	80.9	<0.001	1.41 (1.14: 1.74)	0.002
Area					
Asian	2	76.6	0.039	1.55 (1.11: 2.16)	0.010
European	5	0	0.449	1.51 (1.25: 1.82)	<0.001
American	1	NA	NA	1.03 (0.96: 1.10)	0.395
Study design					
CSS	7	83.5	<0.001	1.41 (1.13: 1.76)	0.002
PCS	1	NA	NA	1.42 (0.56: 3.59)	0.459
Gender					
Mixed	2	0	0.499	1.03 (0.96: 1.10)	0.366
Female	3	0	0.938	1.83 (1.51: 2.22)	<0.001
Male	3	0	0.699	1.32 (1.14: 1.52)	<0.001
Multivariate analysis					
Yes	8	80.9	<0.001	1.41 (1.14: 1.74)	0.002
No	0	NA	NA	NA	NA
CG/VG	7	96.2	<0.001	1.44 (1.02: 2.05)	0.038
Area					
European	2	68.1	0.077	1.57 (1.15: 2.14)	0.004
American	5	97.4	<0.001	1.39 (0.88: 2.19)	0.154
Study design					
CSS	6	96.7	<0.001	1.53 (1.01: 2.31)	0.044
PCS	1	NA	NA	1.04 (0.89: 1.22)	0.626
Gender					
Mixed	3	60.0	0.082	0.97 (0.82: 1.15)	0.723
Female	2	94.8	<0.001	1.82 (1.04: 3.16)	0.035
Male	2	0	0.963	1.86 (1.59: 2.17)	<0.001
Multivariate analysis					
Yes	5	88.5	<0.001	1.21 (0.93: 1.58)	0.151
No	2	78.1	0.033	2.12 (1.65: 2.73)	<0.001
IU/MP	7	36.9	0.147	1.90 (1.62: 2.21)	<0.001
Area					
Asian	2	0	0.488	1.73 (1.53: 1.96)	<0.001
European	2	73.6	0.052	2.19 (1.45: 3.29)	<0.001
Australia	2	0	0.733	1.75 (1.27: 2.42)	0.001
American	1	NA	NA	1.67 (1.10: 2.54)	0.016
Study design					
CSS	7	36.9	0.147	1.90 (1.62: 2.21)	<0.001
PCS	0	NA	NA	NA	NA
Gender					
Mixed	3	0	0.775	1.73 (1.54: 1.94)	<0.001
Female	2	57.1	0.127	2.28 (1.59: 3.27)	<0.001
Male	2	0	0.823	1.72 (1.30: 2.27)	<0.001
Multivariate analysis					
Yes	7	36.9	0.147	1.90 (1.62: 2.21)	<0.001
No	0	NA	NA	NA	NA

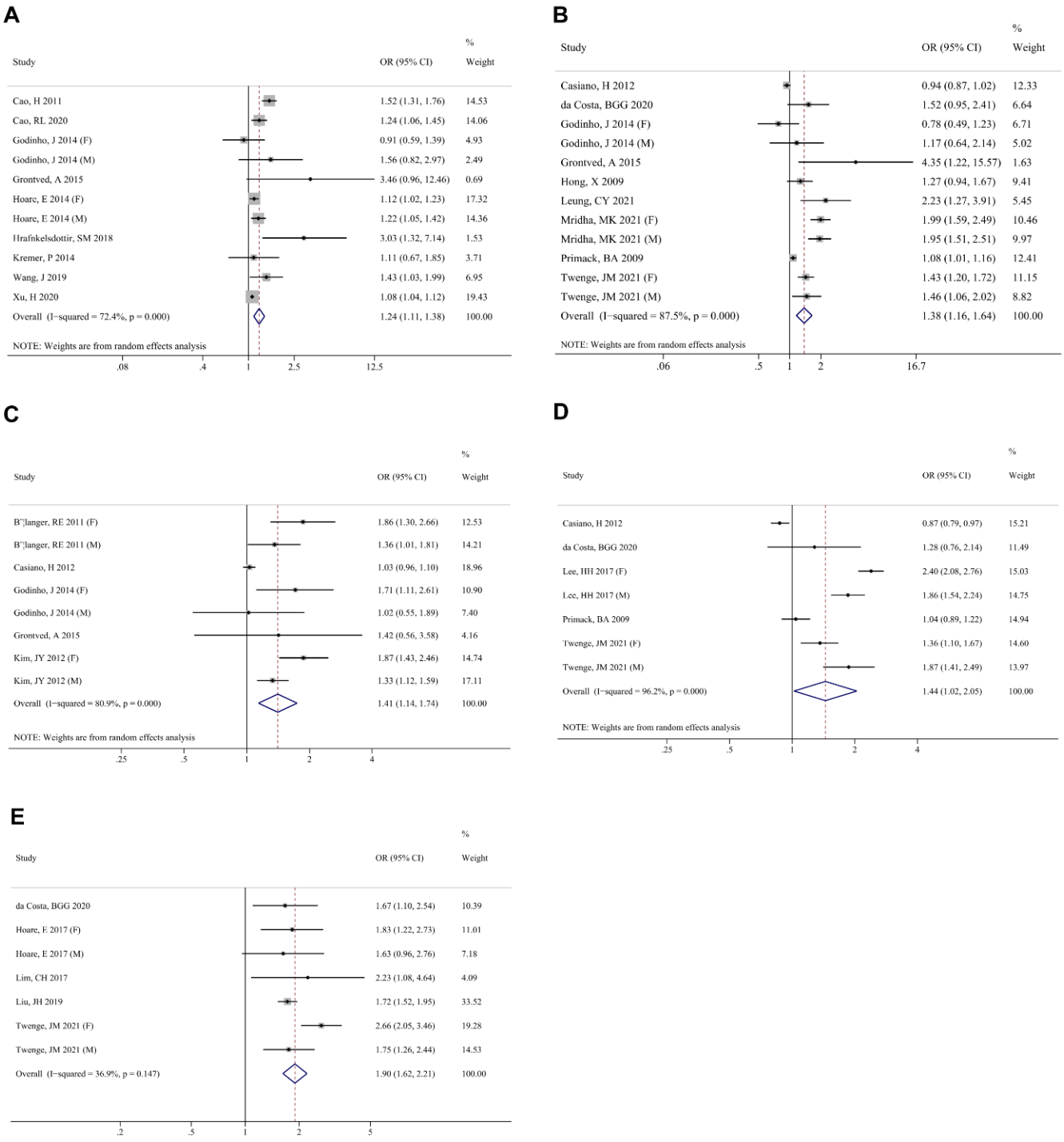

Figure 2. Results for meta-analysis. The forest plots show the reuslts for screen time (ST, A), watching television (TV, B), computer use (CU, C), computer game/ video game (CG/VG, D), and internet use/ mobile phone (IU/MP, E).

suggested that when ST exceeded a certain time, the risk of depression was positively associated with ST-based sedentary behavior. On the other hand, when TV time was limited to 0.5-1.5 hours/day, TV was associated with a decreased risk of depression, and the lowest risk was screened at TV of 1.5 hours/day. Similarly, when CU time was limited to 0-0.5 hours/day, CU was associated with a decreased risk of depression, and the lowest risk was screened at CU of 0.5 hours/day. However, CG/VG and IU/MP did not show this pattern. These results suggested that TV and CU might improve children's and adolescents' ability to read and visualize images when TV time limited to 0.5-1.5 hours/day and CU time limited to 0-0.5 hours/day.

Additionally, Liu et al. [16] also performed a meta-analysis to explore the association between ST-based sedentary behavior and depression in children and adolescents, which revealed that ST is associated with depression risk in a non-linear dose–response manner in children and adolescents. Our present meta-analysis differs from theirs in several ways. Firstly, their study included16 articles containing 127,714 participants, and our present study included 22 articles containing 197,673 participants. Secondly, part contents of their study used estimation methods to obtain OR (95%CI), which might lead to inaccurate results. Thirdly, the associations between TV time and depression, CU time and depression, CG/VG time and

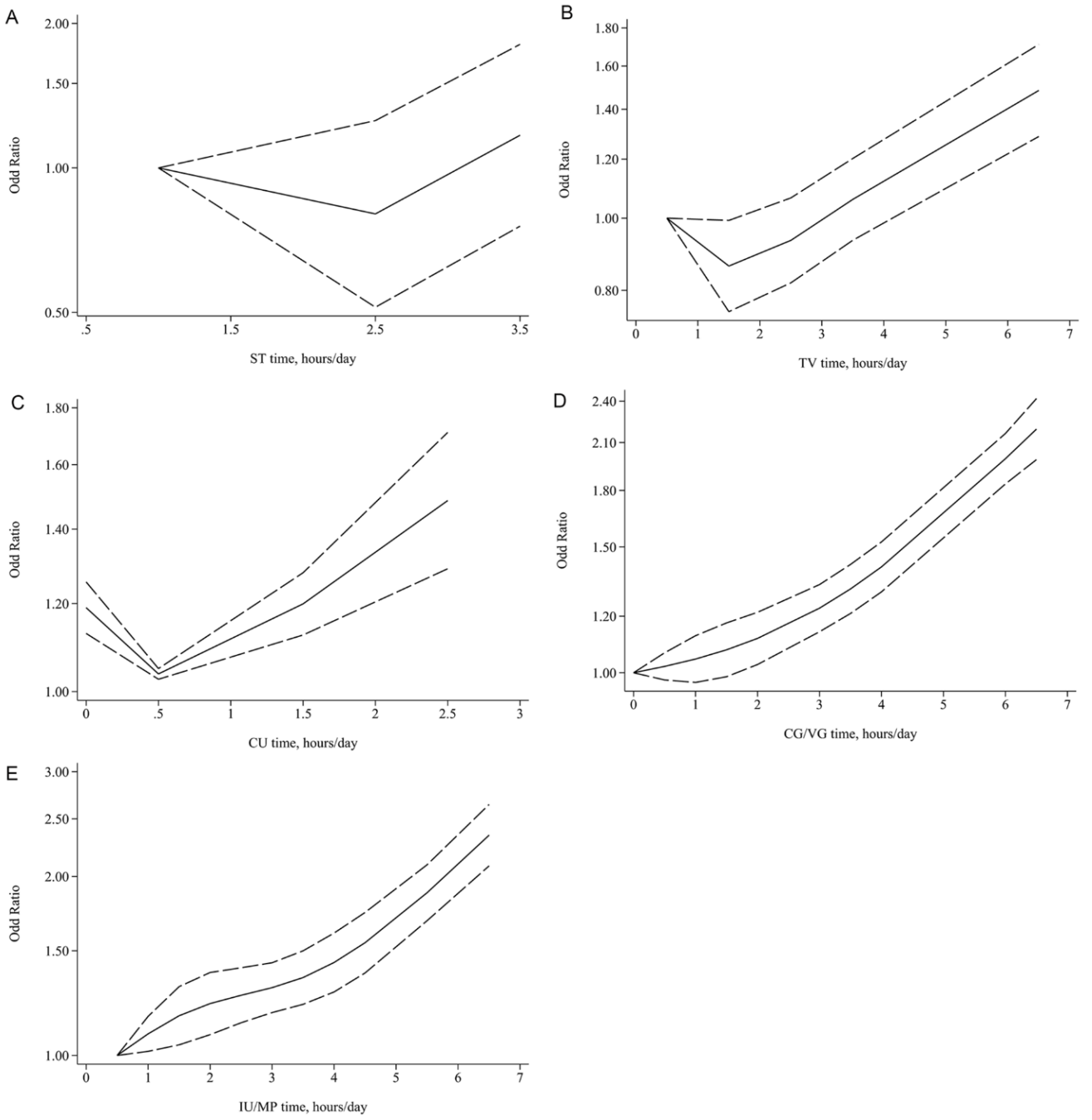

Figure 3: Results of dose-response meta-analysis. Reuslts for screen time (ST, A), watching television (TV, B), computer use (CU, C), computer game/ video game (CG/VG, D), and internet use/ mobile phone (IU/MP, E).

depression, and IU/MP time and depression were revealed separately in our present meta-analysis.

It had some advantages for the present meta-analysis. Firstly, multiple Chinese and English databases were searched, and the number of included studies and sample size was large, increasing the accuracy and credibility of the results. Secondly, dose-response meta-analysis further explored the dynamic association between ST-based sedentary behavior and the risk of depression. Thirdly, the methodological quality of the included studies was moderate, and selection bias, measurement bias and confounding bias were within a reasonable range. Lastly, although some results had significant publication bias, sensitivity analysis suggested that the results of meta-analysis were stable.

However, there were several limitations should be addressed. For example, the statistical heterogeneity among the included studies was significant, and the subgroup analysis failed to accurately find the source of the heterogeneity. The measurement tools and threshold of depression among the included studies were inconsistent, which had a certain impact on heterogeneity. Most of the indicators had been included in few studies and publication bias could not be tested. The sample size was small, and thus the extrapolation of the combined results was limited. Additionally, the included studies were cross-sectional studies and prospective cohort studies. Most studies performed multivariate analysis to adjust for the influence of confounding factors on the results, but the inconsistency of the correction factors would bring heterogeneity to the results.

In summary, ST-based sedentary behavior was associated with the risk of depression in a non-linear dose–response manner for children and adolescents. To be specific, when TV time beyond 4.5 hours/day, TV time was associated with a higher risk of depression, and less TV time may be correlated with a lower risk of depression. When CU time beyond 0.5 hours/day, CU time was associated with a higher risk of depression, and less CU time may be correlated with a lower risk of depression. The risk of depression increased with increasing CG/VG time and IU/MP time when time beyond 2 hours/day and 0.5 hours/day, respectively. Thus, excessive TV, CU, CG/VG, and IU/MP may be harmful for the health, and parents should limit the ST of children and adolescents. However, because of the limitations of the present meta-analysis, furthermore comprehensive studies are needed.

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