Are Active Video Games Useful In The Development Of Fundamental Movement Skill Of Non-Typically Developing Children?A Meta-Analysis

Sen Li
Shanghai University of Sport
Yang Song
Rizhao Sports School
Zhidong Cai
Shanghai University of Sport
Qingwen Zhang (zqw@lixin.edu.cn)
Shanghai University of Sport https://orcid.org/0000-0002-0016-4940

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Abstract

Background

Active video games are increasingly used in sports rehabilitation, especially among children and adolescents. However, due to the variety of video games, the different intervention environments and intervention doses, there are often differences in treatment effects. There may be questions about the actual effectiveness of video games in sports rehabilitation. This study systematically evaluated the effect of active video games on the development of basic motor skills in children and adolescents with atypical development.

Methods

The literature in seven Chinese and English databases was retrieved from randomized controlled trials. The included studies were quantitatively evaluated using the PEDro Scale. Relevant data were then input and analyzed using Review Manager version 5.4.

Results

Seventeen papers were included. In the three subordinate concepts of fundamental movement skill, Active Video Games could significantly improve locomotor skill(standardized mean difference = 0.59, 95% confidence interval 0.38–0.80, $P < 0.0001$) and stability skill(standardized mean difference = 0.59, 95% confidence interval 0.17–1.00, $P = 0.006$) in non-typically developing children.But there was no significant difference compared with the control group(standardized mean difference = 0.11, 95% confidence interval − 0.49–0.72, $P = 0.72$) in object control skill.

Conclusions

The study shows that Active Video Games can improve locomotor skill and stability skill in non-typically developing children, but the effect on object control skill is uncertain, and more high-quality literature needs to be included in the future.

Background

Motor development is one of the most basic and important areas of individual development[1]. However, not all children have opportunities for typical development. Motor skill deficits are key characteristics of several non-typically developing children (NTDC) [2], such as cerebral palsy, autism spectrum disorder, and developmental coordination disorder, and are often accompanied by various degrees of damage to the brain or central nervous system disorders(CNSD), mainly manifested as developmental delay, poor balance, and coordination of movements.

During childhood, the central nervous system exhibits great neural plasticity; therefore, high-intensity physical therapy interventions at this stage can enhance rehabilitation outcomes[3]. Rehabilitation programs have shown positive effects for children with Cerebral palsy (CP), with 30–45 min sessions every day, which seems to be necessary for neuroplasticity[4–6]. Regardless of what is taken, the repetition of a motor task is fundamental to improving motor control during rehabilitation[7].The level of motor skills is low for NTDC, and the highly structured and repetitive activities of traditional rehabilitation have difficulty adhering to and motivating participation[8].The rehabilitation process is an exhaustive process that may cause psychological fatigue[9]. This might have negative effects on children in the form of boredom and decreased motivation to continue the interventions[10–11].A potential area of intervention may lie in the attractiveness of play and children's preference for and participation in technology[12].

“Active video games” (AVGs), realize sports entertainment with the help of high-tech technologies, such as human–computer interaction, motion sensing, and virtual reality[13]. About the differences between AVGs and traditional rehabilitation medicine, Levac et al summarized several “active ingredients” that AVGs can provide to help children improve in rehabilitation[14], including:AVGs enhance problem solving and cognitive participation in the game process, and enhances the changes of motivation and neural plasticity;create repetitive task oriented and task specific practices in an ecologically effective virtual environment that is similar to the real world and provides flexibility to adjust task difficulty, visual and/or auditory feedback, and social game and interaction potential; provide social support from parents, peers or therapists.Through these attributes, AVGs can effectively improve the child’s impaired body structure and function and influence the child’s“personal factors” (eg, increased motivation and confidence).It can be seen that AVGs are very suitable as rehabilitation tools for NTDC.

Considering that AVGs require gross motor activity, the influence of AVGs on the movements of gross motor has gradually become the focus of scholars' attention[15–16], and has gradually developed into a popular therapy for motor skill intervention for special populations[17].However, different video game platforms and intervention doses may have different effects on the NTDC motor skills. If these problems are not solved, the promotion and application of AVGs in the field of medical rehabilitation will be greatly restricted. This study aimed to explore the effect of AVGs on Fundamental Movement Skill (FMS) development of NTDC by employing meta-analysis. FMS mainly include three dimensions: locomotor skill(LS), object control skill(OCS) ,and stability skill(SS). Additionally, the effects of the AVG intervention plan (including intervention platforms,intervention time, intervention frequency, and intervention cycle) on the FMS of NTDC were further determined.

Methods

Criteria for including studies

The inclusion criteria were as follows: (i) the study population was aged 3–14 years with NTDC, (ii) at least one of the FMSs was objectively measured and reported separately, (iii) the intervention in the study was conducted using an AVG platform and was not a single intervention, (iv) the study was published and peer-reviewed in English or Chinese , and (v) the study was a randomized controlled trial (RCT).

Criteria for excluding studies

The exclusion criteria were as follows: (i) subjects were children and adolescents with physical disabilities or who had not been informed clearly, (ii) evaluation of motor skill is a combination of gross motor skill and fine motor skill, (iii) data on the change in FMS before and after the test (e.g., mean ± SD) were absent, and (iv) the subjects were not 3-14 years old.

Outcome indicators

(i) LS index, including walking, running, jumping, shuttle run, etc., (ii) OCS index, including throwing, catching, hitting, and beating, and (iii) SS index, including balance beam standing, on one or both feet, etc.

Literature-retrieval strategy

The following databases were used: PubMed, Cochrane Library, Embase, Elton Bryson Stephens Company, Web of Science, China National Knowledge Infrastructure, and Wanfang. We retrieved data from RCTs from the inception of each database until March 16, 2021.

The search strategy was based on principles of PICOS (population, intervention, comparison, outcomes, and study design). We employed three groups and used their search terms.

Group 1 was based on AVGs: “active video gam*” OR “exergam*” OR “virtual realit*” OR “virtual therap*” OR “virtual environment*” OR “video gam*” OR “computer gam*” OR “serious gam*” OR “Wii” OR “Kinect” OR “PlayStation” OR “EyeToy” OR “GestureTek” OR “IREX”.

Group 2 was based on balance: “gross motor” OR “motor coordination” OR “motor skill” OR “movement skill” OR “fundamental motor skill” OR “fundamental motor skill” OR “fundamental movement skill” OR “motion capture” OR “balance”.

Group 3 was based on the subject: “Child*” OR “boys and girls*” OR “student” OR “youth” OR “teen” OR “young person” OR “preschool”.

Literature screening

Two researchers used independent double-blind methods to screen the literature based on the inclusion and exclusion criteria stated above, and relevant data were extracted. If there was a disagreement in the review, screening, and data-extraction stages, a third researcher discussed whether to include the data[18].

Data extraction

The data extracted from the literature were the author names, year of publication, and basic characteristics of the samples (gaming platform, game type, outcome indicators, and intervention environment/period/duration/ frequency) (Table 1).

Quality evaluation

Two researchers independently judged the risk degree of the literature according to the seven areas of the Cochrane system evaluation manual: random sequence generation (selective bias), allocation concealment (selective bias), blind method of subjects and researchers(performance bias), blind method of outcome evaluator (detection bias), incomplete outcome data (attrition bias), selective reporting (reporting bias) and other bias. For each index, “low bias risk”, “uncertainty bias risk” and “high bias risk” are used for judgment. If the evaluation results are inconsistent, the third researcher shall be consulted appropriately to reach an agreement and finally determine the literature quality.

Statistical analyses

We employed Review Manager 5.4 for data processing. The boundary values of “small”, “medium”, and “large” effect sizes were 0.2, 0.5, and 0.8[19].Also, 75%, 50%, and 25% denoted the proportion of “high”,“medium” and “low” inter-study heterogeneity, respectively[20].If significant heterogeneity between studies was not observed ($P > 0.1$, $I^2 < 40\%$), we used a fixed-effects model for analysis. If there was significant heterogeneity between studies ($P< 0.1$, $I^2 \geq 40\%$), a random-effects model was used for analyses, and further subgroup analyses were carried out to discover the source of heterogeneity.

If ≥2 tasks were used to measure the FMS of NTDC, the effect size was selected from the most commonly used tasks[21], if the study reported multiple measurements on the same task (e.g., the ability to balance in the left, right, front, and back directions), the standard deviation and variance were averaged to represent the outcome of the task[22].

Results

A total of 1840 Chinese and English studies were obtained from seven Chinese and English databases. Six studies were added through other means, so 1846 studies were imported into Endnote™ X9. After removing duplicates, 1052 studies were obtained. A total of 705 studies were removed after reading the titles and abstracts, leaving 347 studies. The full text has been read. According to the inclusion and exclusion criteria stated above, 17 studies using RCTs were included: 11 were written in English and 6 in Chinese (Figure 1). The characteristics of the studies are presented in Table 1. The 17 studies included 594 subjects. Overall (male and female) samples were used in all studies, and the sex ratios were approximately equal.

Bias Risk Analysis of the Included Literature

As shown in Figures 2 and 3, Review Manager software was used to analyze the risk of bias in the included literature.Among these papers, 12 papers did not explain the method of random allocation of subjects, and only 3 papers used the method of allocation and hiding to randomly divide the subjects.3 papers blinded the subjects and 7 papers conducted the blinding of evaluation, among which 2 papers conducted double-blinded experiments on both subjects and result evaluation. Data of the 17 papers were complete, and other sources of bias risk were not explained. It can be seen from Figure 2 and 3 that the included papers has a certain risk of bias.

Meta-analysis of the intervention effects of AVGs on LS in NTDC

Eleven RCTs were included in the study on the intervention of AVGs on the LS of NTDC, including 389 subjects(Figure 4). Heterogeneity test results showed that the difference was statistically significant, indicating that AVGs could significantly improve the speed and agility of NTDC, and the LS were significantly improved compared with the control group. A subgroup analysis of potential moderators was conducted to further explore the sources of potential heterogeneity (Table 2).

Meta-analysis of the intervention effects of AVGs on OCS in NTDC

Five studies reported the intervention effect of AVGs on OCS of NTDC(Figure 5).The heterogeneity test showed the difference was not statistically significant. This indicates that AVGs did not significantly improve the OCS of NTDC compared with the control group.

Meta-analysis of the intervention effects of AVGs on SS in NTDC

AVGs were the most widely studied intervention on SS of NTDC, and fourteen randomized controlled experiments were included in the study on the intervention of AVGs on on SS of NTDC, including 425 subjects(Figure 6).The heterogeneity test showed the difference was statistically significant, indicating that AVGs could significantly improve SS of NTDC, and the SS were significantly improved compared with the control group. A subgroup analysis of potential moderators was conducted to further explore the sources of potential heterogeneity (Table 3).

Discussion

This review aimed to examine the intervention effects of AVGs on FMS development in NTDC. Seventeen RCTs were included in our meta-analysis, of which 11 were related to LS, 5 to OCS, and 14 to SS. Overall, AVGs showed the effectiveness of intervention on FMS in NTDC, however, for the three subordinate concepts of FMS, there were some differences in the intervention effect of AVGs.

Analyses of the intervention effect of AVGs on LS of NTDC

A meta-analysis of 11 studies included in this study with LS as an indicator showed that AVG had a significant effect on LS of NTDC (SMD=0.59). AVG is an interactive and personalized treatment method that can present the required environment and provide immediate feedback. By providing immediate feedback, virtual reality environments can elicit multisensory interactions that motivate and engage patients in longer and more intensive sessions[38]. On the one hand, repetitive motor practice promotes neuroplasticity, on the other hand, in video game training, the standing posture is often used to complete a lot of weight fluctuation control, standing squatting, standing sitting, and other exercises, which require constant weight transfer between the lower limbs. This had a significant impact on the participants' lower limb strength and joint flexibility. These findings have promoted the continuous improvement of participants' LS, which is consistent with the results of a study conducted by Wuang et al.on 155 patients with Down syndrome aged 7-12 years[39].

However, some studies have shown that although the AVGs intervention group showed a greater trend of improvement compared with the control group, the difference between the two groups was not significant[2,17].This possibly because the intervention group did not provide participants with sufficient exercise intensity. AVGs have rich resources and the regulation of task difficulty, can improve participants' interest in practice, increased the amount of physical activity. Studies have shown that high-intensity repetition exercises can improve the physical function of the exercisers and produce better training results[40].Therefore, higher exercise intensity is required to achieve significant improvement in body function. At the same time, the literature included in the previous systematic evaluation studies was not randomized controlled experimental studies,[2] and the literature quality was not high, so the conclusions may have some limitations.

Analyses of the intervention effect of AVGs on OCS of NTDC

There is a general lack of research on how AVGs interfere with the OCS of NTDC, and recent studies have shown varying results[2].There were only five studies on OCS included in this study, and the intervention effect was limited, which does not support its significant improvement in OCS.

The physical activities in these games include motor tasks that involve a wide range of sensory feedback,and visual feedback is dominant.Although AVGs can simulate rich real-world scenes, tactile is difficult to be fully practiced and developed in this simulation environment. Tactile is the feeling produced when contacting external stimuli, which is different from LS and SS, they require tactile stimulation to provide real-world experience, require upper or lower limbs to contact objects for object control, and perform actions such as throwing, slapping, and kicking. In this process, the touch between the body and object plays an important role, which is difficult to replicate in virtual reality technology. Neither the game handle in hand nor the controller worn on the body can provide timely haptic feedback, such as the weight and size of the control object.Therefore, some scholars began toproposal use haptic feedback gloves when using video games to simulate ball operations in real life. By wearing gloves, participants can timely feed back more haptic information to improve the intervention effect of AVGs on OCSs[41].

Although the overall effect of AVGs on improving OCS in this study was not significant, Chiu et al. showed that the range and frequency of use of children's upper limbs have a significant increase compared with the past after video game intervention[27], which greatly improves their independence level in daily activities[9].This undoubtedly has an important impact on the development and improvement of upper limb function in NTDC.

Analyses of the intervention effect of AVGs on SS of NTDC

Among the 17 studies included in this review, SS was the most concentrated (14 studies), and the intervention effect was also obvious (SMD=0.59). Visual feedback theory provides theoretical hypotheses for video games boosting participants' balance skills. The theory holds that when playing video games, children can see their actions on the video screen immediately, which constitutes a new effective learning method, implicit learning[42].

The tasks practiced during video games incorporate a wide range of visual–perceptual processing[43].The visual timely feedback enables the participants to continuously adjust and control the position of the body during the game. It enhanced the frequency and intensity of visual feedback, allowing participants to continuously perform posture detection and balance disturbance correction in response to different balance conditions. Meanwhile, the games exercises completed in the standing position increased the stability of the participants' trunk, the symmetry on both sides of the body was improved, the center of gravity of the body was evenly distributed on the lower limbs, the stability of standing was increased, and the ability of posture control was improved[44,45].

It is worth noting that when using AVGs to intervene in the SS of NTDC, attention should be paid to the control of exercise intensity and trying to avoid heavy load exercise in a short time. Ruzic et al. found that high-intensity exhaustive exercise load has a negative impact on both static and dynamic balance ability after studying the relationship between exercise load and balance ability with healthy people as samples[46]. Although no similar study has been conducted on NTDC, it deserves our attention. With regard to exercise load, there may be some differences between the interventions of SS and LS, which requires more scientific experimental design and research based on different intensities in the future.

Moderating variable analysis of intervention effect of AVGs on FMS of NTDC

In this study, there was no significant difference in the improvement of OCS, therefore, only the LS and SS subgroups were analyzed. The subgroup analysis of the intervention effect on the LS of NTDC shows that the game intervention platforms are widely distributed, including Nintendo Wii, Xbox 360 Kinect, Q4 Scene Interactive Training System, and KMC1 virtual reality movement system. From the perspective of disease types and intervention settings, the intervention effect for children with cerebral palsy in medical and clinical institutions is more obvious, the conclusions of the intervention cycle, single intervention duration, and intervention frequency are relatively consistent, that is, the longer intervention cycle and intervention duration, as well as the higher intervention frequency every week, have a greater effect on the intervention effect of LS in NTDC.

The subgroup analysis of the intervention effect on SS of NTDC shows that research on intervention with Nintendo Wii games is the most concentrated. The Nintendo Wii balance platform is specially developed for balance games, and the intervention effect is also obvious,For children with CP, the effect of intervention in medical and clinical institutions is obvious, which is consistent with LS, In terms of intervention cycle, single intervention duration and intervention frequency, SS show different conclusions from LS. Short-term, high-frequency, and long-term interventions have more obvious effects on the SS of NTDC.

Due to the portable characteristics of video games, intervention treatment is not limited to specific clinical medical institutions but is gradually extended to schools and families. However, the results of this study found that the intervention effect in family and school environments was not significant, and the reason may be related to the degree of personalized support and guidance[41]. When children play sports video games without any guidance, their skill execution ability is poor[16].In terms of intervention cycle, single intervention duration, and intervention frequency, there were certain differences in LS and SS in the subgroup analysis, mainly reflected in the unk dose of intervention. In the past, few studies have discussed the ideal frequency of AVG intervention in motor skill development[2], because other characteristics included in the study are different, which will also lead to some differences in intervention results. Therefore, it is difficult to identify the specific and scientific intervention doses. However, from the perspective of children's interest maintenance, long-term and high-frequency video game intervention (30 min of training every day within 20 weeks) is not conducive to the maintenance of children's learning interest and will make it difficult for participants to complete the intervention task[47].

Conclusions

The use of video games as a form of rehabilitation incorporates fundamental elements of motor learning[48].AVGs provide a safe and interesting environment, produce less fatigue, and greater load intensity and total amount by the body, which increases the physical activity level of game participants and improves the practice effect. The results of this study show that AVGs are an effective rehabilitation treatment tool for the intervention of FMS in NTDC. Especially in stability and locomotor skills, the research conclusions are relatively consistent, and the intervention effects reach a medium effect. However, AVGs as a way of action intervention for NTDC need to be further studied because of the limitations of existing research. At present, the impact of AVGs on motor skills rarely involves the consideration of exercise intensity. Intensity plays an important role in the acquisition and remodelling of motor skills. Future research should strengthen the consideration of the exercise intensity of AVGs, draw a more specific activity dose, and provide clear guidance and help for healthy or special people.

Abbreviations

NTDC
Non-typically developing children
CNSD

Central nervous system disorders
AVGs
Active video games
FMS
Fundamental movement skill
CP
Cerebral palsy
RCT
Randomized controlled trial
LS
Locomotor skill
OCS
Object control skill
SS
Stability skill

Declarations

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Authors' contributions

Each author made significant individual contributions to this manuscript. Li(0000-0002-8859-1292): systematic searching, study quality scoring, data extraction, analysis and drafting manuscript and creating tables and figures, Song (0000-0003-2615-8220): screened the literature according to the inclusion and exclusion criteria, Cai(0000-0002-9901-6349): screened the literature according to the inclusion and exclusion criteria,Qingwen Zhang (0000-0002-8885-1066): resolved discrepancies between Song and Cai regarding inclusion of studies, provided suggestions for modifying the manuscript. All the authors approved the final version of the manuscript.

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Availability of data and materials

All data analysed for this review are included in this published article .

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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Tables

Table 1. List of basic characteristics of the included documents.

Researchers	Subjects		Disease Types	Intervention Setting	AVGs Platform	AVGs Category	Control group	Intervention			Outcom
	E/C	Age (y)						Cycle	Time	Frequency	Indicato
Alsaif[23] et al. 2015	20/20	6-10	CP	Home	Nintendo Wii Fit	Unreported	Non-intervention	12	20	7	MABC, BOT-2
Arnoni[24] et al. 2019	7/8	5-14	CP	Unreported	Xbox 360 Kinect	Jumping ,Loading exercises	Regular Exercise	8	45	2	GMFM-
Chen[25] et al. 2013	15/15	3-6	CP	Medical Clinic	Q4 Scene Interactive Training System	Billiard Ball, Hopscotch	Regular Exercise	12	30	5	BBS,GM
Chen[26] et al. 2016	20/20	3-6	CP	Medical Clinic	Q4 Scene Interactive Training System	Billiard Ball, Hopscotch	Regular Exercise	12	40	5	BBS,GM
Chiu[27] et al. 2014	30/27	6-13	CP	Home	Nintendo Wii Sports	Bowling, Aerial sports, Frisbee and Basketball	Regular treatment	6	40	3	TT
Ferguson [28] et al. 2013	19/27	6-10	DCD	School	Nintendo Wii Fit	Imitation game, Mobile game, and Arm movement games	Neuromotor task training	6	30	3	MABC2
Mombarg [29] et al. 2013	15/14	7-12	DCD	School	Nintendo Wii Balance Board	Ski-jump, Segway circuit, Obstacle course,Skate boarding	Non-intervention	6	30	3	MABC2
Neto[30] et al. 2019	16/16	7-10	DCD	Medical Clinic	Nintendo Wii Console and Balance Board	Table Tennis, Frisbee, Archery, Bowling,Tightrope walk and Marble balance	Task-Specific matched Training	8	60	2	MABC2
Pourazar [31] et al. 2019	10/10	7-12	CP	Medical Clinic	Xbox 360 Kinect	Dance rehabilitation training	Regular treatment	6	85-100	1	SEBT
Ren[32] et al. 2016	19/16	3-6	CP	Medical Clinic	Q4 Scene Interactive Training System	Unreported	Regular Exercise+ Occupational Therapy	12	40	5	BBS,GM
Rojas[7] et al. 2017	16/16	7-14	CP	Rehabilitation centre	Nintendo Wii Balance Board	Snowboard, Penguin Slide, Super Hula Hoop,Yoga	Standard Physiotherapy	6	30	3	COP
Salem[17] et al. 2012	20/20	3-5	DCD	Medical Clinic	Nintendo Wii Sports and Fit	Balance, Walking, Strength, Weight bearing, Aerobics	Routine Physiotherapy	10	30	2	10WT, TUGT, GMFM
Urgen[33] et al. 2016	15/15	7-14	CP	Unreported	Nintendo Wii Fit	Jogging plus, Penguin slide, Heading, Ski jump, Snowball fight, Tilt city, Perfect 10, Segway circuit play	Routine Physiotherapy and Rehabilitation	9	45	2	GMFM, PBS, TUGT
Uysal[34] et al. 2016	12/12	6-14	CP	Rehabilitation centre	Nintendo Wii Balance	Basketball, Tennis, Boxing	Routine Physiotherapy	12	30	2	PBS
Zhang[35] et al. 2019	20/20	3-6	CP	Rehabilitation centre	KMC1	Cycling game	Regular treatment	12	20	5	GMFM-
Zhao(a)[36] et al. 2018	21/21	3-6	CP	Rehabilitation centre	Xbox 360 Kinect	Boxing, Javelin bowling , Universe bubble ball,Bounce ball	Regular treatment	3	40	5	GMFM-QUEST
Zhao(b)[37] et al.2018	21/21	3-6	CP	Rehabilitation centre	Xbox 360 Kinect	Dance music imitation	Regular treatment	3	40	5	GMFM-

E= experimental group, C= control group, CP= cerebral palsy, DCD= developmental coordination disorder, MABC-2= Movement Assessment Battery for Children-2, BBS = Berg Balance Scale, PBS = Pediatric Balance Scale, TUGT = Timed Get Up and Go Test, COP = Center of Pressure, FFRT= Functional Forward Reach Test, BOT = Bruininks–Oseretsky Test of Motor Proficiency, QUEST=Quality of Upper Extremity Skill Test, 10ST=10 Step Test, 20mSRT=20 Meter Shuttle Run Test, ①Locomotor Skills, ②Object Control Skills, ③Stability Skills.

Table 2. Subgroup analyses of the intervention effects of AVGs on LS of NTDC

Moderator variable	Subgroup	Included literature	Heterogeneity test			Effect size	95% CI	Two-tailed test	
			χ^2	P	I^2			Z	P
Gaming platform	Nintendo Wii™	4	3.34	0.34	10%	0.23	（-0.10,0.56）	1.38	0.17
	Xbox™ 360	3	0.58	0.75	0%	0.71	（0.30,1.12）	3.40	**0.0007****
	Q4 Scene Interactive Training System	3	3.20	0.20	37%	0.92	（0.51,1.33）	4.41	**＜0.0001****
	KMC1	1	0	0.00	0	0.84	（0.19,1.49）	2.53	**0.01***
Disease type	CP	8	4.43	0.73	0%	0.80	（0.55,1.05）	6.31	**＜0.0001****
	DCD	3	1.66	0.44	0%	0.12	（-0.25,0.49）	0.65	0.51
Intervention setting	School	2	0.20	0.65	0%	-0.04	（-0.50,0.41）	0.18	0.85
	Medical institutions	7	4.86	0.56	0%	0.78	（0.53,1.03）	6.14	**0.01***
Intervention cycle	≤8 weeks	5	6.55	0.16	39%	0.38	（0.07,0.68）	2.41	**0.02***
	9-12 weeks	6	4.90	0.43	0%	0.77	（0.49,1.05）	5.39	**＜0.00001****
Duration of single intervention	≤30 min	5	7.40	0.12	40%	0.39	（0.10,0.69）	2.61	**0.009****
	≥40 min	6	2.78	0.73	0%	0.57	（0.29,0.86）	3.93	**＜0.0001****
Intervention frequency	＜3 times/week	3	0.32	0.85	0%	0.50	（0.07,0.94）	2.27	**0.02***
	3-5 times/week	8	14.45	0.04	52%	0.64	（0.30,0.98）	3.69	**0.0002****

*:p<0.05, **:p<0.01.

Table 3. Subgroup analyses of the intervention effects of AVGs on SS of NTDC

Moderator variable	Subgroup	Included literature	Heterogeneity test			Effect size	95% CI	Two-tailed test	
			χ^2	P	I^2			Z	P
Gaming platform	Nintendo Wii™	8	26.20	0.0005	73%	0.34	[0.08,0.60]	2.54	**0.01***
	Xbox™ 360	3	24	< 0.00001	92%	1.81	[-0.41,4.03]	1.60	0.11
	Q4 Scene Interactive Training System	3	0.23	0.89	0%	0.58	[0.19,0.97]	2.90	**0.004****
Disease type	CP	10	28.42	0.0008	68%	0.83	[0.38,1.28]	3.63	**0.0003****
	DCD	4	8.10	0.04	63%	-0.06	[-0.66,0.54]	0.19	0.85
Intervention setting	School and Home	3	11.61	0.003	83%	0.23	[-0.69,1.15]	0.49	0.62
	Medical institutions	9	36.01	<0.0001	78%	0.84	[0.28,1.40]	2.93	**0.003****
Intervention cycle	≤8 weeks	7	40.30	< 0.00001	85%	0.51	[-0.27,1.29]	1.28	0.20
	9-12 weeks	7	4.36	0.63	0%	0.74	[0.46,1.02]	5.11	**<0.00001****
Duration of single intervention	≤30 min	7	19.83	0.003	70%	0.58	[0.07,1.09]	2.25	**0.02***
	≥40 min	7	32.34	<0.0001	81%	0.65	[-0.07,1.37]	1.77	0.08
Intervention frequency	<3 times/week	6	36.98	< 0.00001	86%	1.01	[-0.09,2.10]	1.80	0.07
	3-5 times/week	8	15.35	0.03	54%	0.47	[0.12,0.82]	2.63	**0.009****

*:p<0.05, **:p<0.01

Figures

Figure 1

The flow chart of literature screening

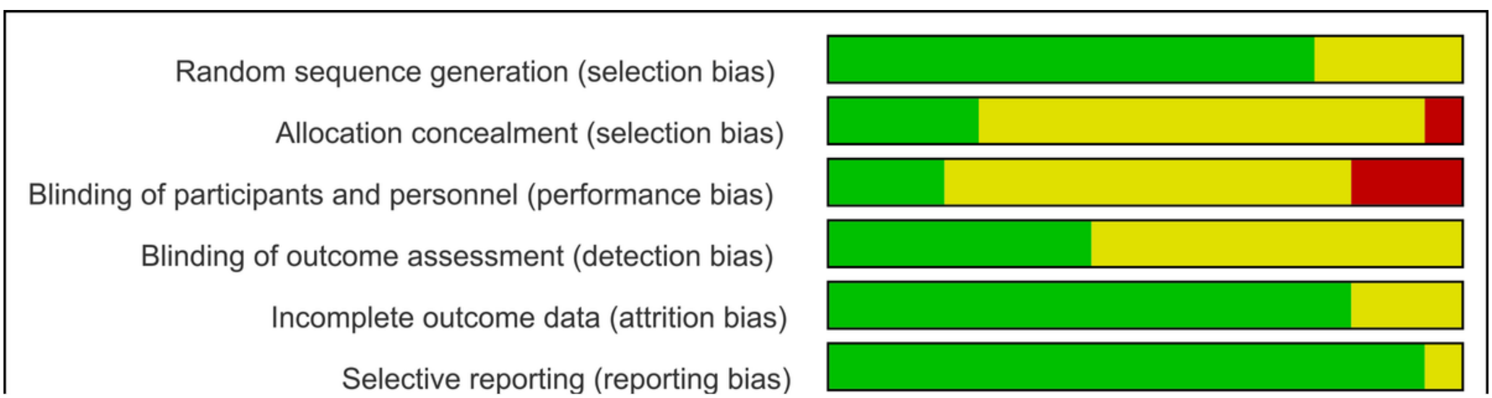

Figure 2

The overall risk of bias of the included papers

Figure 3

The risk of bias of the included papers

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Fixed, 95% CI
Arnoni 2019	89.64	7.21	7	85.23	14.45	8	4.0%	0.36 [-0.67, 1.38]
chen 2013	41.17	11.75	15	32.15	6.46	15	7.4%	0.93 [0.17, 1.68]
chen 2016	37.16	9.51	20	32.51	7.02	20	10.6%	0.55 [-0.09, 1.18]
Ferguson 2013	1.61	0.92	19	1.74	1.05	27	12.3%	-0.13 [-0.72, 0.46]
Mombarg 2013	5.9	1	15	5.8	1.2	14	8.0%	0.09 [-0.64, 0.82]
Ren 2016	40	11	19	27	5	16	7.4%	1.44 [0.69, 2.20]
Salem 2012	0.91	0.09	20	0.87	0.09	20	10.8%	0.44 [-0.19, 1.06]
Urgen 2016	53.96	17.46	15	41.78	17.95	15	7.8%	0.67 [-0.07, 1.41]
Zhang 2019	47	5.89	20	42.4	4.84	20	10.1%	0.84 [0.19, 1.49]
Zhao (a) 2018	72.79	9.96	21	65.1	10.73	21	10.8%	0.73 [0.10, 1.36]
Zhao (b) 2018	29.19	8.19	21	24.03	2.98	21	10.6%	0.82 [0.19, 1.45]
Total (95% CI)			**192**			**197**	**100.0%**	**0.59 [0.38, 0.80]**

Heterogeneity: Chi² = 14.97, df = 10 (P = 0.13); I² = 33%
Test for overall effect: Z = 5.60 (P < 0.00001)

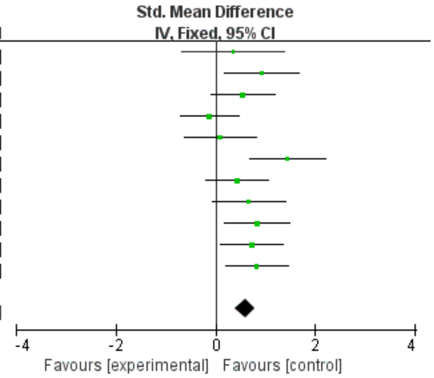

Figure 4

Effects of AVGs on the LS of NTDC

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Alsaif, A.A 2015	9.84	1.79	20	8.11	1.89	20	19.6%	0.92 [0.27, 1.58]
Chiu 2014	0.26	0.21	30	0.25	0.2	27	21.4%	0.05 [-0.47, 0.57]
Ferguson 2013	6.84	3.18	19	8.52	2.44	27	20.3%	-0.60 [-1.20, 0.00]
Neto 2019	14.18	4.51	16	17.43	6.18	16	18.8%	-0.59 [-1.30, 0.12]
Zhao(a) 2018	16.38	7.07	21	11.75	4.36	21	19.9%	0.77 [0.14, 1.40]
Total (95% CI)			**106**			**111**	**100.0%**	**0.11 [-0.49, 0.72]**

Heterogeneity: Tau² = 0.38; Chi² = 19.22, df = 4 (P = 0.0007); I² = 79%
Test for overall effect: Z = 0.37 (P = 0.71)

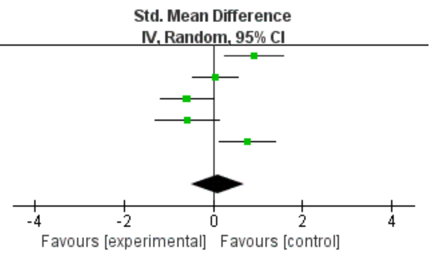

Figure 5

Effects of AVGs on the OCS of NTDC

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Alsaif, A.A 2015	16.1	3.1	20	12.7	3.74	20	8.0%	0.97 [0.31, 1.63]
Arnoni 2019	-3.47	2.6	7	-3.09	2.25	8	6.2%	-0.15 [-1.16, 0.87]
Chen 2013	41.71	5.57	15	37.82	7.15	15	7.6%	0.59 [-0.14, 1.32]
Chen 2016	41.25	6.28	20	37.8	7.91	20	8.1%	0.47 [-0.16, 1.10]
Ferguson 2013	8.11	2.47	19	9.48	2.31	27	8.3%	-0.57 [-1.17, 0.03]
Mombarg 2013	4.75	1.4	15	4.25	1.7	14	7.6%	0.31 [-0.42, 1.05]
Neto 2019	27.62	9.33	16	31.31	3.7	16	7.7%	-0.51 [-1.21, 0.20]
Pourazar 2019	57.2	1.8	10	45.23	2.03	10	2.6%	5.98 [3.73, 8.22]
Ren 2016	43	6	19	38	8	16	7.8%	0.70 [0.01, 1.39]
Rojas 2017	-3.51	0.75	16	-4.19	0.9	16	7.7%	0.80 [0.08, 1.52]
Salem 2012	4.1	1.5	10	3.1	1	10	6.7%	0.75 [-0.16, 1.67]
Urgen 2016	110.49	55.99	10	86.89	49.41	10	6.8%	0.43 [-0.46, 1.32]
Uysal 2016	55.75	0.45	12	53.91	1.62	12	6.7%	1.49 [0.57, 2.42]
Zhao(b) 2018	44.05	6.98	21	39.67	7.4	21	8.2%	0.60 [-0.02, 1.22]
Total (95% CI)			**210**			**215**	**100.0%**	**0.59 [0.17, 1.00]**

Heterogeneity: Tau² = 0.45; Chi² = 52.34, df = 13 (P < 0.00001); I² = 75%
Test for overall effect: Z = 2.76 (P = 0.006)

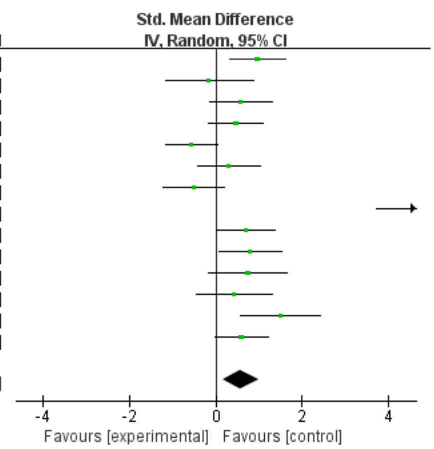

Figure 6

Effects of AVGs on the SS of NTDC