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Effect of video games training on the gross motor skills of children with cerebral palsy: systematic review and meta-analysis.

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Key words: video games training; gross motor skills; cerebral palsy; intervention; randomized controlled trial.

Abstract. The purpose of this work was to systematically evaluate the intervention effects of video games training (VGT) on the gross motor skills (GMS) development of children with cerebral palsy (CP). Seven Chinese and English databases (PubMed, Embase, Web of Science, Cochrane Library, China National Knowledge Infrastructure, Wanfang, EBSCO) were searched. Data were retrieved from randomized controlled trials on the GMS among individuals with CP. The retrieval was from the inception of each database to March 16, 2021. The included studies were evaluated quantitatively using the PEDro Scale. Then, relevant data were inputted and analyzed in Review Manager 5.4. Thirteen papers were included: seven written in English and six in Chinese. In the three subordinate concept of GMS, VGT could significantly improve locomotor skills (LS) (standardized mean difference = 0.80, 95% confidence interval 0.55–105, P<0.00001), and non-locomotor skills (NLS) (standardized mean difference = 0.83, 95% confidence interval 0.38–1.28, P=0.0003) in CP. However, there was no significant difference in object control skills (OCS), when compared with the control group (standardized mean difference = 0.55, 95% confidence interval -0.01–0.72, P=0.05). VGT can improve LS and NLS in CP, but the effect on OCS is uncertain; therefore, it is recommended that additional high-quality literature be included in the future. In general, VGT has been proven an effective intervention tool on the GMS development in CP.

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Efecto del entrenamiento con videojuegos en la motricidad gruesa de niños con parálisis cerebral: revisión sistemática y meta-análisis.

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Palabras clave: entrenamiento con videojuegos; habilidades motoras gruesas; parálisis cerebral; intervención; prueba controlada aleatoria.

Resumen. Este artículo intentó evaluar sistemáticamente el efecto de la intervención del entrenamiento con videojuegos (VGT) en el desarrollo de las habilidades motoras gruesas (GMS) de niños con parálisis cerebral (CP), basándose en un cuerpo de datos logrado de las conclusiones de pruebas controladas aleatorias sobre las habilidades motoras gruesas de niños con CP, obtenidos de la búsqueda sistemática en siete bases de datos chinos y extranjeros, tales como PubMed, Embase, Web of Science, Cochrane Library, China National Knowledge Infrastructure, Wanfang y EBSCO. El lapso de búsqueda fue desde la fecha de establecimiento de cada base de datos hasta el 16 de marzo del 2021. Se aplicó la escala PEDro para realizar un estudio cuantitativo y después, se analizaron los datos relevantes con Review Manager 5.4. Se incluyeron 13 publicaciones, 7 artículos escritos en inglés y 6 en chino. En el marco del concepto de los tres subordinados de GMS, la VGT podría mejorar significativamente la habilidad locomotora (LS) (diferencia de medias estandarizada = 0.80, intervalo de confianza del 95%: 0.55-105, P<0.00001), y las habilidades no locomotoras (NLS) (diferencia de medias estandarizada = 0.83, intervalo de confianza del 95%: 0.38-1.28, P= 0,0003) en PC; pero no hubo una diferencia significativa en las habilidades de control de objetos (OCS), cuando se compararon con el grupo control (diferencia de medias estandarizada= 0,55, intervalo de confianza del 95% -0,01-0,72, P= 0,05). En conclusión, el VGT puede mejorar las LS y NLS en CP, pero el efecto sobre OCS es incierto; por lo que se recomienda la inclusión de literatura adicional de alta calidad en el futuro. De este modo se pudo demostrar que el VGT es una herramienta de intervención eficaz en el desarrollo de las GMS en niños con CP.

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INTRODUCTION

Cerebral palsy (CP), is a group of persistent central motor and postural developmental disorders and activity limitation syndrome, which is caused by non-progressive brain damage in developing fetuses or infants [1]. According to the statistics of the World Health Organization (WHO), the incidence rate of CP is around 0.2%-0.3% worldwide, and there are more than forty thousand new CP children in China every year [2]. Most of the children with CP have problems such as dyskinesia, abnormal posture and abnormal hemiplegic gait [3]. The damage to the advanced central nervous system of children with CP may cause secondary injuries, such as physical spasm, amyotrophy, skeletal deformities and developmental coordination disorder, which constrain the children's ability to move, thereby impacting upon their development of gross motor skills (GMS) [4-6]. The good development of GMS will promote children and adolescents to participate in activities actively, but the GMS disorder is an important factor hindering children with CP from participating in physical activities [7]. If they do not participate in physical activities for a long time, children with CP will not only lag behind their peers in strength, coordination and endurance, but also face the risk of many mental diseases, such as depression, social phobia, and so on [8]. Therefore, it is very important to pay attention to the development of GMS in children with CP.

People pay great attention to and support various sports activities to improve the physique and abilities of special groups [9]. The quantity and quality of motor experience are important for brain plasticity and functional recovery [10], so motor skill intervention is often provided to develop the gross motor function of children with CP. However, traditional motor intervention therapy often requires the help of various games and facilities, and requires a large activity space and experienced therapists to accurately control the treatment process, so as to ensure the participants' interest in the treatment process and the smooth progress of the treatment [6]. Most importantly, the level of motor skills of children with CP is very poor, and the highly structured and repetitive activities of traditional rehabilitation are difficult to adhere to and to motivate their participation [11]. A potential area of intervention may lie in the attractiveness of playing and children's preference for and participation in technology [12].

"Active video games" (AVGs), also known as "exergaming" or "virtual reality games" realize sports entertainment with the help of high-tech technologies, such as human–computer interaction, motion sensing and virtual reality [13]. AVGs can provide an ecological environment similar to that in the real world, where participants can practice specific tasks, and the difficulty of tasks can be adjusted readily in the game and provide sufficient challenges [14]. Such immersive experience in a safe, enjoyable, and playful environment is associated with less fatigue and more relaxation, which may attract children, including those with CP [15]. Simultaneously, due to the characteristics and animation effects of the game, it can also increase children's motivation and participation in the gaming process, attract users to immerse themselves in the sports environment [16], and improve their cognitive function and motor skills. Hence, video games training (VGT) are very suitable as rehabilitation tools for children, and gradually have developed into a popular therapy of motor skill intervention for special populations [17]. A review of the literature on children with cerebral palsy suggests that AVGs interventions can improve GMS development, including their balance, coordination and other physical fitness [18].

Many scholars have done research on video game training to improve the GMS of children with CP. However, the past research often focused on one aspect of GMS, such as the impact on stability skills, the impact on upper limb skills, etc., and they lack of a summary and discussion of the effects of video games to improve the overall GMS of children with CP. GMS refers to the movement generated by large muscles or muscle groups of the body, including walking, running, jumping, throwing, etc. According to the change of spatial position and the control of external tools, the GMS can be divided into locomotor skills (LS), object control skills (OCS) and non-locomotor skills (NLS) [19]. It can be seen that GMS is a general term that includes three subordinate concepts. This research was aimed to explore the effects of VGT on the GMS development of children with CP by employing a systematic review and meta-analysis, and demonstrate the effectiveness of VGT in intervening the three subordinate concepts of GMS in children with CP. In addition, if one aspect of

GMS is significantly improved, the dose effect of intervention duration, intervention frequency and intervention cycle will be discussed by subgroup analysis.

METHODS

Criteria for including studies

The criteria for including literature were: (i) the study population was aged 3–14 years with CP; (ii) at least one of GMS was objectively measured and reported separately; (iii) the intervention was not a single intervention; (iv) the study was published and peer-reviewed in English or Chinese; (v) the study was a randomized controlled trial (RCT).

Criteria for excluding studies

The criteria for excluding studies were: (i) evaluation of motor skill is a combination of gross motor skill and fine motor skill; (ii) data on the change of GMS before and after the test (e.g., mean ± SD) were absent; (iii) the subjects were not 3-14 years old.

Outcome indicators

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

Literature-retrieval strategy

The databases we used were PubMed, Cochrane Library, Embase, Elton Bryson Stephens Company, Web of Science, China National Knowledge Infrastructure, and Wanfang. We retrieved data from randomized controlled trials (RCTs) from the inception of each database to March 16, 2021.

The search strategy was based on the principle of PICOS (Population, Intervention, Comparison, Outcomes and Study design). We employed three groups and used search terms for them.

Group 1 was based on VGT: “active video game*”（视频游戏）, OR “exergam*”, （体感游戏）OR “virtual realit*” OR “virtual therap*”, OR “virtual environment*”, OR “video game*”, OR “computer game*”, OR “serious gam*”, OR “Wii”, OR “Kinect”, OR “PlayStation”, OR “EyeToy”, OR “GestureTek”, OR “IREX”.

Group 2 was based on GMS: “gross motor”（粗大动作）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: “children with CP” (脑瘫儿童), OR “children with cerebral palsy” (脑性瘫痪儿童), OR “spastic diplegia*”, OR“spastic diplegic”, OR“spastic quadriplegic”.

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 on the review, screening, and data-extraction stages, a third researcher discussed whether to include the data.

Data extraction

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

Quality evaluation

All the literature included in our study consisted of RCTs. The PEDro Scale was used for evaluation of literature quality, and comprised 11 items. The PEDro scale has a total score of 10 points: <4 indicates “poor” quality; 4–5 indicates “medium” quality; 6–8 indicates “good” quality; 9–10 indicates “high” quality (Table 2).

Table 1
List of basic characteristics of the included documents.

Researchers	Subjects		Intervention Setting	AVGs Platform	AVGs Category	Control group	Intervention			Outcome Indicators	GMS
	E/C	Age (y)					Cycle	Time	Frequency		
Alsaif *et al.* (24) 2015	20/20	6-10	Home	Nintendo Wii Fit	Unreported	Non-intervention	12	20	7	MABC, BOT-2	②③
Arnoni *et al.* (25) 2019	7/8	5-14	Unreported	Xbox 360 Kinect	Jumping, Loading exercises	Regular Exercise	8	45	2	GMFM-88, BSA	①③
Chen *et al.* (26) 2013	15/15	3-6	Medical Clinic	Q4 Scene Interactive Training System	Billiard Ball, Hopscotch	Regular Exercise	12	30	5	BBS,GMFM-88	①③
Chen *et al.* (27) 2016	20/20	3-6	Medical Clinic	Q4 Scene Interactive Training System	Billiard Ball, Hopscotch	Regular Exercise	12	40	5	BBS,GMFM-88	①③
Chiu *et al.* (28) 2014	30/27	6-13	Home	Nintendo Wii Sports	Bowling, Aerial sports, Frisbee and Basketball	Regular treatment	6	40	3	TT	②
Pourazar *et al.* (29) 2019	10/10	7-12	Medical Clinic	Xbox 360 Kinect	Dance rehabilitation training	Regular treatment	6	85-100	1	SEBT	③
Ren *et al.* (30) 2016	19/16	3-6	Medical Clinic	Q4 Scene Interactive Training System	Unreported	Regular Exercise+ Occupational Therapy	12	40	5	BBS,GMFM-88	①③
Rojas *et al.* (31) 2017	16/16	7-14	Rehabilitation centre	Nintendo Wii Balance Board	Snowboard, Penguin Slide, Super Hula Hoop,Yoga	Standard Physiotherapy	6	30	3	COP	③

Table 1
CONTINUATION

Researchers	Subjects		Intervention Setting	AVGs Platform	AVGs Category	Control group	Intervention			Outcome Indicators	GMS
	E/C	Age (y)					Cycle	Time	Frequency		
Urgen *et al.* (32) 2016	15/15	7-14	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	①③
Uysal *et al.* (33) 2016	12/12	6-14	Rehabilitation centre	Nintendo Wii Balance	Basketball, Tennis, Boxing	Routine Physiotherapy	12	30	2	PBS	③
Zhang *et al.* (2) 2019	20/20	3-6	Rehabilitation centre	KMC1	Cycling game	Regular treatment	12	20	5	GMFM-88	①
Zhao(a) *et al.* (34) 2018	21/21	3-6	Rehabilitation centre	Xbox 360 Kinect	Boxing, Javelin bowling , Universe bubble ball,Bounce ball	Regular treatment	3	40	5	GMFM-88, QUEST	①②
Zhao(b) *et al.* (35) 2018	21/21	3-6	Rehabilitation centre	Xbox 360 Kinect	Dance music imitation	Regular treatment	3	40	5	GMFM-88, PBS	①③

E= Experimental group; C= Control group; CP = cerebral palsy; 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; BOT = Bruininks–Oseretsky Test of Motor Proficiency; QUEST=Quality of Upper Extremity Skill Test; ①Locomotor Skills; ②Object Control Skills; ③Non-locomotor skills.

Table 2
Methodological Quality Assessment for Included Studies.

Included Studies	A	B	C	D	E	F	G	H	I	J	K	Score
Alsaif *et al*. 2015	1	1	0	1	0	0	0	1	1	1	1	6
Arnoni *et al*. 2019	1	1	1	1	1	1	0	1	1	1	0	8
Chen *et al*. 2013	1	1	0	1	0	0	0	1	1	1	1	6
Chen *et al*. 2016	1	1	0	1	0	0	0	1	1	1	1	6
Chiu *et al*. 2014	1	1	0	1	0	0	1	1	1	1	1	7
Pourazar *et al*. 2019	1	1	0	1	1	1	0	1	1	1	0	7
Ren *et al*. 2016	1	1	0	1	0	0	0	1	1	1	1	6
Rojas *et al*. 2017	1	1	0	1	0	0	0	1	1	1	1	6
Urgen *et al*. 2016	1	1	0	1	0	0	0	1	1	1	0	5
Uysal *et al*. 2016	1	1	0	1	0	1	0	1	1	1	1	7
Zhang *et al*. 2019	1	1	0	1	0	0	0	1	1	1	1	6
Zhao(a) *et al*. 2018	1	1	0	1	0	0	0	1	1	1	1	6
Zhao(b) *et al*. 2018	1	1	1	0	0	0	0	1	1	1	1	6

a. eligibility criteria were specified; b. subjects were allocated randomly to groups; c. allocation was concealed; d. the groups were similar at baseline with regard to the most important outcome indicators; e. there was blinding of all subjects; f. there was blinding of all therapists; g. there was blinding of all assessors; h. measures of at least one key outcome were obtained from >85% of subjects initially allocated to groups; i. all subjects for whom outcome measures were available received treatment or, if this was not the case, data for at least one key outcome were analyzed by intention-to-treat; j. the results of between-group statistical comparisons were reported for at least one key outcome; k. the study provided point measures and measures of variability for at least one key outcome.

Statistical analyses

We employed Review Manager 5.4 for data processing. The boundary value of "small", "medium", and "large" effect sizes was 0.2, 0.5, and 0.8 [20]. Also, 75%, 50%, and 25% denoted the proportion of "high", "medium" and "low" inter-study heterogeneity, respectively [21]. If significant heterogeneity between the studies was not observed ($P > 0.1$, $I^2 < 40$ %), then we used a fixed-effects model for analyses. If there was significant heterogeneity between studies ($P< 0.1$, $I^2 \geq 40\%$), then a random-effects model was used for analyses, and further subgroup analyses were carried out to discover the source of heterogeneity.

If ≥2 tasks had been used to measure the GMS of CP, the effect size is selected from the most commonly used tasks [22]. If the study reported multiple measurements on the same task (e.g., the ability to balance in left, right, front, and back directions), the standard deviation and variance were averaged to represent the outcome of the task [23].

RESULTS

Literature characteristics

A total of 840 Chinese and English studies were obtained from seven Chinese and English databases. Six studies were added through other means, so 846 studies were imported into Endnote™ X9 (https://endnote.com/). After removal of duplicates, 631 studies were obtained. Then, 126 studies were removed after reading the title and abstract, which left 113 studies. Then, the full text was read. According to the inclusion and exclusion criteria stated above, 13 studies using RCTs were included: seven written in English and six in Chinese (Fig. 1). The

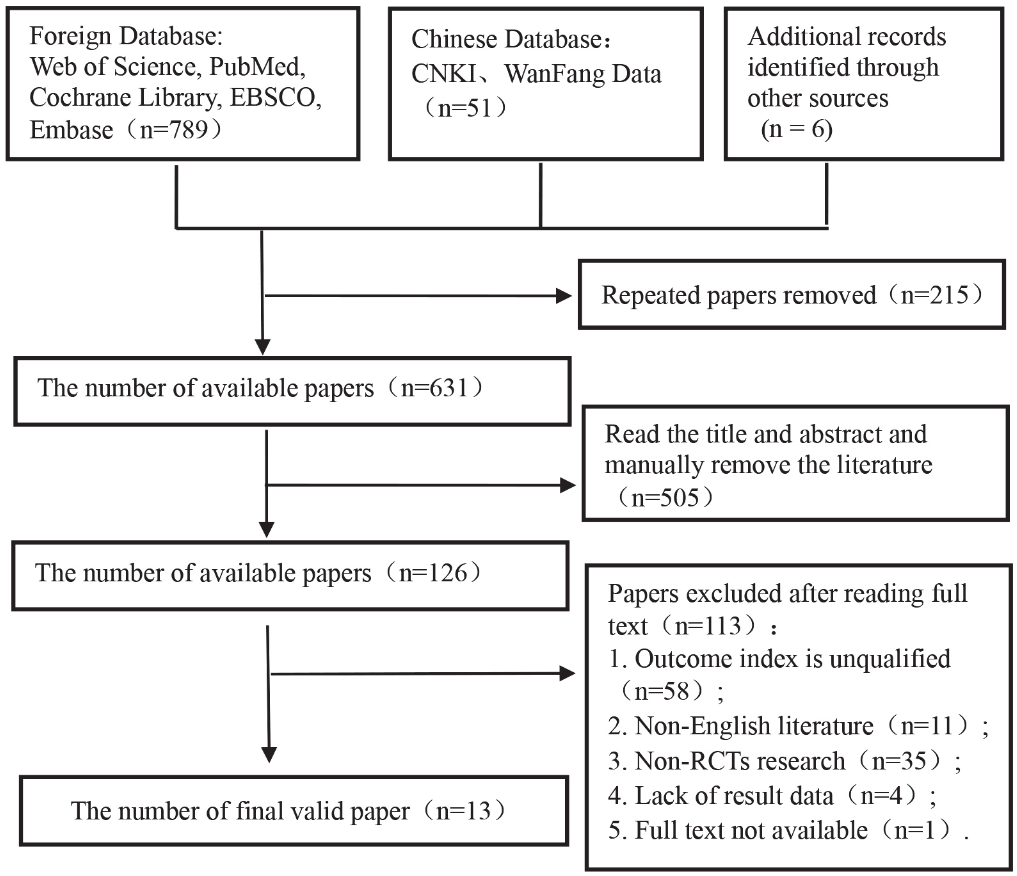

Fig. 1. The flow chart of literature screening.

characteristics of the studies are shown in Table 1.

The 13 studies involved 447 subjects. Overall (male and female) samples were used in all studies, and the sex ratio was approximately equal. The sample size of one study was >50, in the other 12 studies it was between 20 and 40. In our meta-analysis, Nintendo (Kyoto, Japan) Wii™ was the dominant and most frequently used gaming platform. Five studies used Nintendo gaming platforms, including Wii Balance, Wii Fit (or Wii Fit Plus) and Wii Sports. The KMC1 (INNOVAID, Denmark) virtual situational movement system was used in one studies ,Q4 Scene Interactive Training System was used in three studies, and four studies used the Xbox™ 360 gaming platform from Microsoft (Redmond, WA, USA). Except for two studies that did not mention explicitly the intervention environment, medical institutions such as rehabilitation hospitals and children's clinics were the main intervention venues (nine studies) and two studies used family homes as the intervention environments.

In terms of the types of active video games, it covered almost all sports, including routine sports such as dancing, table tennis, basketball, boxing, bowling, ski jumping, obstacle course, skateboarding and so on. Compared with traditional sports intervention methods, the content scope of games is broader, providing more choice space for participants.

Literature Quality Evaluation

Among the 13 RCTs, only one study was rated as "medium" quality (PEDro Scale score = 5), and the other 12 studies were rated between 6 and 8, all of which denoted "good" quality. The most prevalent problem in the included RCTs was a lack of blinding. A lack of blinding in the subject intervention or evaluation of the final outcome can increase the risk of bias in the selection and evaluation of participants, and may impinge an artificial influence on the experimental results [36]. The quality evaluation of studies included in our meta-analysis is shown in Table 2.

RESULTS OF META-ANALYSIS

Meta-analysis of the intervention effects of VGT on LS of Children with CP

Eight randomized controlled experiments were included in the study on the intervention of VGT on LS of CP, including 274 subjects. The analysis results are shown in Fig. 2. Heterogeneity test results showed that there was low heterogeneity between studies (X^2=4.43, I^2=0%, P=0.73), the fixed-effect model was used to combine effect size and effect size [SMD=0.80, 95%CI(0.55,1.05), P<0.00001], the difference was statistically significant, indicating that VGT could significantly improve the LS of CP, and the LS were significantly improved compared with the control group. To further explore the source of potential heterogeneity, a subgroup analysis of potential moderators was conducted (Table 3).

Meta-analysis of the intervention effects of VGT on OCS of Children with CP

Only three studies reported the intervention effect of AVGs on OCS of children with CP. The heterogeneity test showed (Fig. 3) a high degree of heterogeneity between studies (X^2 = 5.21, I^2 = 62%, P = 0.07), the random-effect model was used to combine effect size and effect size [SMD=0.55,95%CI(-0.01,0.72),p=0.05], the difference was not statistically significant. Indicating that VGT had no significant difference in improving OCS of Children with CP when compared with the control group.

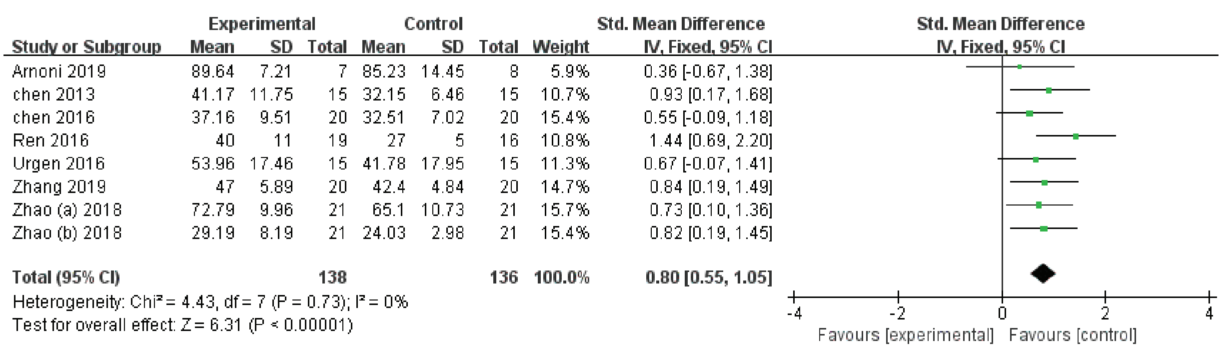

Fig. 2. Effects of VGT on LS of Children with CP.

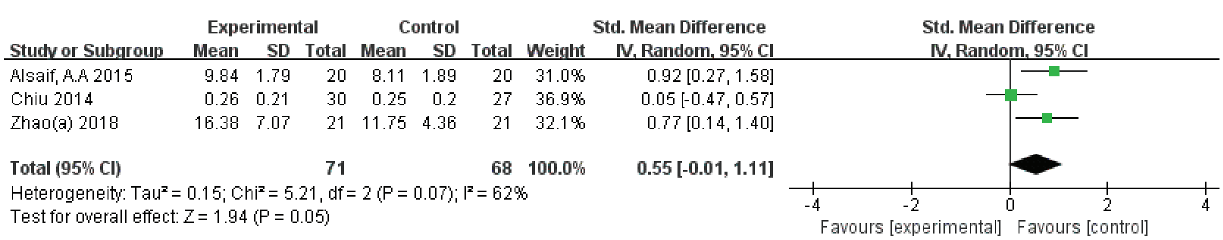

Fig. 3. Effects of VGT on OCS of Children with CP.

Table 3
Subgroup analyses of the intervention effects of VGT on LS of Children with CP.

Moderator variable	Subgroup	Included literature	Heterogeneity test			Effect size	95% CI	Two-tailed test	
			χ2	P	I2			Z	P
Gaming platform	Nintendo Wii™	1	0	0.00	0	0.67	(-0.07,1.41)	1.78	0.08
	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%	0.94	(0.42,1.46)	3.54	**0.0004****
	KMC1	1	0	0.00	0	0.84	(0.19,1.49)	2.53	**0.01***
Intervention cycle	≤8 weeks	3	0.58	0.75	0%	0.71	(0.30,1.12)	3.40	**0.0007****
	9-12 weeks	5	3.53	0.47	0%	0.85	(0.54,1.17)	5.35	**<0.00001****
Duration of single intervention	≤30 min	2	0.03	0.86	0%	0.87	(0.38,1.37)	3.47	**0.0005****
	≥40 min	6	2.78	0.73	0%	0.57	(0.29,0.86)	3.93	**<0.0001****
Intervention frequency	<3 times/week	2	0.24	0.63	0%	0.56	(-0.04,1.16)	1.84	0.07
	3-5 times/week	6	3.46	0.63	0%	0.85	(0.58,1.12)	6.10	**<0.00001****

*: $p<0.05$; **: $p<0.01$.

Meta-analysis of the intervention effects of AVGs on NLS of Children with CP.

VGT were the most widely studied intervention on NLS of Children with CP, and 10 randomized controlled experiments were included in the study on the intervention of VGT on NLS of Children with CP, including 298 subjects. The analysis results are shown in Fig. 4. The heterogeneity test showed a high degree of heterogeneity between studies (X^2 = 28.42, I^2 = 68%, P=0.0008), the random-effect model was used to combine effect size and effect size [SMD=0.83,95%CI(0.38,1.28),p=0.0003], the difference was statistically significant, indicating that VGT could significantly improve NLS of Children with CP, and the NLS were significantly improved compared with the control group. To further explore the source of potential heterogeneity, a subgroup analysis of potential moderators was conducted (Table 4).

DISCUSSION

With the continuous development and improvement of virtual-reality technology, VGT are increasingly applied in the field of sports rehabilitation, and the intervention of VGT in special children is centered on the mobility, balance and motor development of children with autism [37-39], CP [23-35] and developmental coordination disorder [40,41]. However, there are few meta-analyses on the intervention of gross motor skills and their subordinate concepts in VGT, and the main purpose of this study is to evaluate quantitatively the results of VGT on the development of GMS in children with CP to verify its intervention effect.

Analyses of the intervention effect of VGT on LS of CP

Locomotor Skills refers to the ability to move and change body direction and position quickly and effectively under control, which requires the integration of independent motor abilities including balance, coordination, speed, reflection, strength and endurance, and is the embodiment of comprehensive ability. Meta-analysis of eight papers included in this study with LS as an indicator, showed that VGT had a significant effect on LS of CP (SMD=0.80). This is consistent with the results of the study conducted by Wuang *et al*. on 155 patients with Down syndrome aged 7-12 years. After a 24-week, 2,880 minute virtual-reality game intervention, they found that the AVGs intervention group showed significant improvements in speed and agility compared with the non-exercise group and the standard occupational therapy group [42].

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,

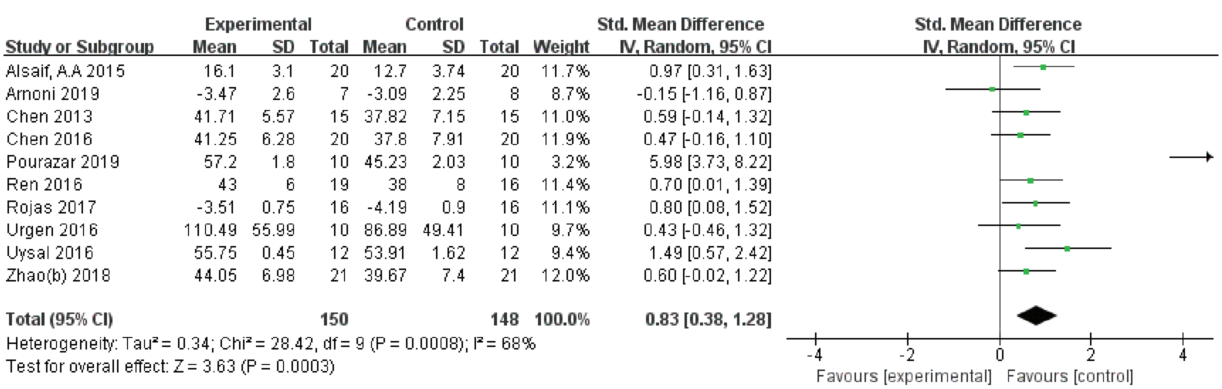

Fig. 4. Effects of VGT on NLS of Children with CP.

Table 4
Subgroup analyses of the intervention effects of VGT on NLS of Children with CP.

Moderator variable	Subgroup	Included literature	Heterogeneity test			Effect size	95% CI	Two-tailed test	
			χ2	P	I2			Z	P
Gaming platform	Nintendo Wii™	4	2.79	0.43	0%	0.91	(0.52,1.30)	4.60	<0.00001**
	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**
Intervention setting	Home	1	0	0	0	0.97	(0.31,1.63)	2.89	0.004**
	Medical institutions	7	24.66	0.0004	76%	1.04	(0.43,1.65)	3.36	0.0008**
Intervention cycle	≤8 weeks	4	24.06	<0.0001	88%	1.34	(0.01,2.68)	1.98	0.04*
	9-12 weeks	6	4.36	0.50	0%	0.74	(0.44,1.04)	4.85	<0.00001**
Duration of single intervention	≤30 min	4	2.38	0.50	0%	0.91	(0.54,1.28)	4.81	<0.00001*
	≥40 min	6	24.49	0.0002	80%	0.86	(0.09,1.62)	2.19	0.03*
Intervention frequency	<3 times/week	4	26.39	<0.00001	89%	1.63	(-0.03,3.29)	1.92	0.06
	3-5 times/week	6	1.39	0.93	0%	0.68	(0.41,0.96)	4.88	<0.00001*

*: $p<0.05$; **: $p<0.01$.

which need to constantly transfer the weight between the lower limbs. All of these stimulated the player's muscle strength, especially the lower limbs, and improved the individual's functional muscle strength. The integrated development of strength, balance, and coordination, coupled with the continuous involvement of neural networks and cognitive components, as well as visual or auditory feedback, triggered positive neuroplasticity changes in participants [13]. These are important reasons to improve the speed and agility of participants.

Analyses of the intervention effect of VGt on OCS of CP

There is a general lack of research on how AVGs interfere with OCS of CP, and recent studies have shown varied results [43]. There are only three studies on OCS included in this study, and the intervention effect is limited, the conclusion does not support a significant improvement of OCS. The reason for this may be that the OCS are relatively complex. When applying force to an object or intercepting an object, it includes not only the gross motor, such as balance and upper limb coordination, but also the hand-eye coordination and even the flexible ability of fingers, which is the combination of fine motor and gross motor [44]. Simple upper limb or arm movement training has limited impact on tasks requiring hand-eye upper limb coordination.

Another reason may be that OCS 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 the 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 to try to use haptic feedback gloves when using video games to simulate ball operations in real life. By wearing gloves, participants can timely feedback more haptic information, so as to improve the intervention effect of VGT on OCS [45].

Although the overall effect of VGT on improving OCS in this study is not significant, the research of Chiu *et al.* [27] shows that the range and frequency of use of children's upper limbs have a significant increase, compared with the past, after video game intervention, which greatly improves their independence level in daily activities [46], This undoubtedly has an important impact on the development and improvement of upper limb function in CP. Because there is few literature on the impact of VGT on OCS, the conclusions may have some uncertainty.

Analyses of the intervention effect of VGT on NLS of CP

Balance ability is the ability to maintain the human body's posture and is a very important physiological function [47]. Gait instability or difficulty in maintaining balance is an important behavior of many special children, so the intervention of balance ability is an important measure to promote their gross motor. Posture control ability and muscle tension deficiency are considered to be important factors affecting poor gait and balance ability, and AVGs are considered to improve the posture control ability in CP [48]. Among the 13 research literature included in this study, the research on NLS is the most concentrated (10 studies), and the intervention effect was also obvious (SMD=0.83). A reason for the impact of VGT intervention on NLS may be that the AVGs platform is a whole-body interactive video game, which uses sensory motor experiences, such as vision and sound to simulate environment and activities, and its design method can more fully replicate the balance skills of the real world [45]. Using virtual games to perform balance training on the screen provides users with the ability to mirror in real time and adjust their action amplitude, speed and accuracy [27,49]. Lee *et al.* found that virtual reality tools can provide more realistic visual feedback, which is the key to balance and control skills [50].

Video game training requires players to perform fast and accurate local or whole body movements in the standing position, which is very important to promote trunk stability and posture adjustment required for balance during movement [51]. It can significantly improve the symmetry of both sides of the body, make the body center of gravity evenly distributed in the lower limbs, increase the stability of standing, and improve the posture control ability [52]. In a systematic review of groups of CP by Page and colleagues [43], 10 of the 15 studies, that included balance measures, found significant improvement, with the most compelling evidence being for improvement in balance, those data are consistent with the results of our meta-analysis.

Research Limitations

This study had three main limitations. First, only 13 RCTs were included in our meta-analysis. Second, the sample size was relatively small. Third, although the subjects included in the studies all CP, there may be differences in etiology and pathogenesis, and the severity of the disease is inconsistent. The final intervention effect may have been different because of different disease mechanisms.

CONCLUSIONS

VGT provide a safe and interesting environment, produces 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 VGT is an effective rehabilitation treatment tool in the intervention of GMS of CP. Especially in stability skills and locomotor skills, the research conclusions are relatively consistent and the intervention effects results in a large effect. The intervention effect of VGT on OCS is uncertain because there are few studies published. Future research should increase the inclusion of high quality literature and a larger sample size, and it is expected that more scientific conclusions can be drawn on the intervention of VGT in the development of GMS in CP.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Authors' Contributions

All authors contributed to the conception and design of this meta-analysis. YongHe Pan drafted the manuscript. GuangFeng Zhao and Qiang Liu searched the literature and determined which studies should be included and excluded. Sen Li proffered suggestions for modification of the manuscript. All authors approved the final version of the manuscript.

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