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Review

Lower Body Positive Pressure Treadmill Training for pediatric gait disorders: a scoping review

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Abstract: The purpose of this scoping review was to examine the literature on the use of anti-gravity treadmill and its effects on lower limb motor functions in children and adolescents with locomotor impairments. Four databases (MEDLINE, CINAHL, Embase, Web of Science) were searched for articles from inception to August 2021. Inclusion criteria were: (1) experimental or quasi-experimental studies using the anti-gravity training as the primary intervention; (2) studies conducted in paediatricpediatric participants; (3) articles reporting outcomes related to the lower limb functions; and (4) studies published in French or English. Fifteen articles were included in the review. Studies included children and adolescents aged 4–18 years with locomotor impairments. The intervention duration was ranged from 2 and to 12 weeks, with 2-5 sessions per week. Included studies showed reported that anti-gravity training induces improvements in muscle strength, balance, spatiotemporal gait parameters, and walking endurance in children with locomotor impairments. This review provides relevant information about the modalities, outcomes and limits associated with the anti-gravity training protocol reported in the literature. Overall, the anti-gravity treadmill training could be viewed as a valuable training modality for children with cerebral palsy. However, more precise, and comprehensive description of anti-gravity rehabilitation protocols would be useful.

Keywords: Pediatrics, Gait, Rehabilitation, Anti-gravity, Treadmill

1. Introduction

Locomotor impairments in children can result from different causes including cerebral palsy, traumatic brain injury, orthopedic surgery or musculoskeletal pathology. These impairments manifest themselves in various ways, such as a decrease in walking speed (due to a reduced step length and/or cadence), an increase in double support duration, a reduced lower limb range of motion and a poor endurance [1–3]. They can have a detrimental effect on walking capacity, and accordingly affect children social participation and quality of life [4,5]. A priority of physical therapy interventions is therefore to improve gait quality, speed, independence, and efficiency.

Treadmill training is a specific locomotor training modality that promotes massive repetition of the gait movement. Zwicker and Mayson [6] conducted an umbrella review on the effectiveness of treadmill training in children with locomotor impairments. They concluded that treadmill training is overall effective, and no negative outcomes were reported. Partial body weight support (BWS) systems can be used during treadmill training to ensure a safe environment that makes locomotor training easier in children with severe locomotor disorders [7]. These systems can also potentially reduce ground reaction forces (i.e., average and/or peak vertical ground reaction forces), thereby allowing the intensity of training needed for rehabilitation while protecting the lower limb joints [8,9]. Despite their usefulness for gait rehabilitation, it is important to underline the discomfort caused

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by lifting forces provided by the harnesses straps that can impact training sessions duration and hinder a participant's compliance with the training protocol. To address this issue, some innovative BWS treadmill training systems employing lower body positive pressure support have been developed, of which the most widely distributed is the anti-gravity treadmill (AlterG®) [10]. These systems rely on differential air pressure technology, using a chamber on a treadmill allowing the lower body to be supported by the air pressure [11]. It must be noted, however, that this suspension system, despite its name, does not remove gravity per se: overall body weight is reduced, but the actual weight of the lower limbs remains the same. The term 'anti-gravity' will however be used in this review for the sake of simplicity and to differentiate air-pressure body weight supported systems from classical body weight supported system. The anti-gravity treadmill allows users to run or walk while removing up to 80% of their body weight without using a body suspension harness system, which can made rehabilitation easier and earlier. The anti-gravity treadmill training is increasingly used in adults after knee surgery and lower limb sport injuries to reduce ground reaction forces during walking and running to facilitate postoperative rehabilitation [10,12,13]. Despite the promising results concerning this technology, it still requires further investigation to optimize routine clinical use and verify its effectiveness in children with locomotor impairments. The current evidence about its clinical use and effectiveness in pediatric population with locomotor impairments is limited and no synthesis has been produced yet, which could play an important role in guiding future research. Therefore, the aim of the present study was then to perform a scoping review of the literature related to the use of anti-gravity treadmill and to identify profiles of pediatric populations with specific lower limb motor function deficits for which effects have been reported.

2. Materials and Methods

2.1. Data source and literature source

A science librarian was consulted for the initial development of the search protocol. Studies were identified by searching Medline, Embase, CINHAL and Web of Science from inception to August 2021. The search strategy was based on three main concepts: anti-gravity treadmill training, lower limb motor functions and pediatric population. The keywords derived from these terms were adapted for each database (see Appendix S1). The current scoping review follows the guidelines of the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) [14,15]. The study did not require ethical approval.

2.2. Eligibility criteria

The included studies met the following inclusion criteria: 1) experimental or quasi-experimental studies (e.g., randomized controlled trials, before/after studies including single case studies); 2) conducted on (a majority of) pediatric participants ≤19 years; 3) specifically used the anti-gravity training as a primary intervention method for >1 session; 4) articles reporting at least one variable related to lower limb function , and, 5) studies published in French or English. Articles were excluded if they were not original research (e.g., letter to editor, conference abstracts, commentaries).

2.3. Studies screening

Titles and abstracts of the identified studies were screened independently by two of the authors (YC and LP) to identify those that potentially met the inclusion criteria. A full review of the manuscripts was then performed independently by the same authors. In the case of any unresolvable disagreement related to the studies eligibility, a third author (CM) was available.

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2.4. Quality assessment and data extraction

Subsequently, YC and LP independently rated the overall quality of each article included in this study, using the PEDro scale which ranges from 0 to 10 [16]. This scale allows to identify trials that are likely to be valid and have sufficient statistical information to guide clinical decision-making. Each trial report is given a total PEDro score. A calibration meeting was initially performed with five articles, to ensure a clear understanding of each criterion and thus standardization and reliability of assessments. A second meeting was performed to discuss the criteria for each included article, until a consensus was reached for a score. In the case of any unresolvable disagreement, a third author (CM) performed the assessment to reach consensus. Finally, one author (YC) extracted data, including study design and therefore the level of evidence (based on Pedro scale), population characteristics, intervention (and comparison with a control group), intervention parameters, outcomes, and results. Outcomes were classified according to the International Classification of Functioning, Disability and Health (Body structure/function (e.g., muscle power, contractures, spasticity) and Activity domains (e.g., mobility)) [17]. Body structures are defined as anatomical body parts and body functions are the physiological processes of the body and activity for the execution of a specific task or action [17].

3. Results

The database search strategy yield 677 potentially relevant articles. After duplicate removal, processing titles/abstracts and screening the full texts, 15 articles were included in the review (Figure 1).

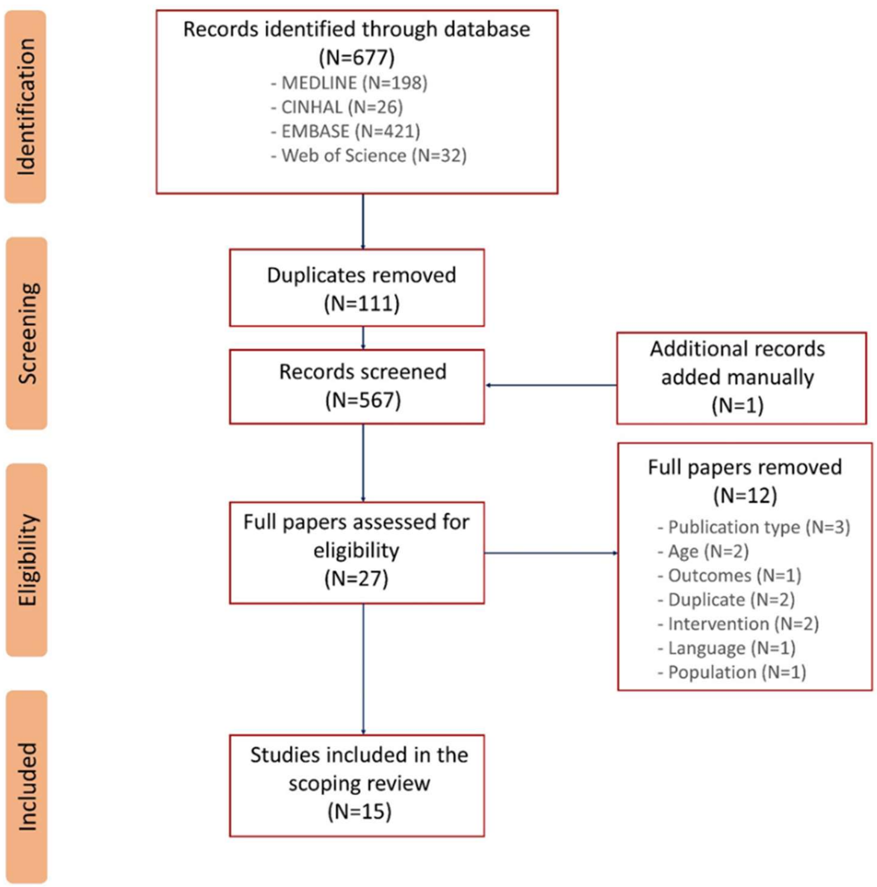

Figure 1. Selection process Prisma Flow Chart.

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3.1. Studies design and quality

Tables 1 and **2** summarize the research design and PEDro rating score. Regarding the study design, we identified six randomized controlled trials (RCT), four multiple cases studies, two before and after studies, one case study, one control case study, and one non-equivalent control-group study. The methodological quality of the included studies ranged from 1 to 8 out of 10, with a median score of 2. Four studies [11,18–20] were of high quality (PEDro score ≥ 6) while the others were of low quality (PEDro score ≤ 3).

3.2. Participant's characteristics

Fourteen of the fifteen studies focused on a pediatric population with cerebral palsy and one study was interested in children with hemophilic knee arthritis. The sample size in the included studies ranged from 1 to 30 participants (total of 185 across all studies), and participants demographics varied considerably (see Table 1). For children with CP, the classification of the participants' movement disorders severity based on the Gross Motor Function Classification System (GMFCS) varied between studies from levels I to IV (at level I children walk, run and jump, but speed, balance and coordination are limited & at level IV children use a wheelchair for propulsion).

3.3. Training protocols

Protocol descriptions are presented in **Table 3**. In three studies, anti-gravity treadmill training was combined with conventional therapy (e.g., stretching and strengthening exercise, physical therapy or occupational therapy focused on walking capacity) [11,18,19]. In the other studies, participants performed training with the anti-gravity treadmill only. Ten studies compared the effect of anti-gravity training to a control intervention such as conventional physical therapy [11,18,19,21], occupational therapy focused on walking capacity [22–26], robotic and BWS treadmill training [20]. The training protocols presented across studies varied in intensity and duration (see **Table 2**). Training was typically conducted with a frequency of two or five times a week, in sessions lasting 20-45 minutes each, for a total intervention duration ranging from 2 to 12 weeks. The settings of the anti-gravity treadmill were relatively similar across the different studies: body weight support was initially set at 30–50%, then decreased progressively; gait speed was initially set at 0.7-1.5km/h and then gradually increased. However, none of the studies reported individual data to describe how settings were progressed.

3.4. Effect of anti-gravity treadmill training on muscle strength, spasticity, and gross motor function

Some studies investigated the effect of anti-gravity training on lower limb muscle strength [18,27,28] and spasticity [26] as well as gross motor function [20]. Few studies assessed muscle strength in isometric [27,28] or concentric mode [18] as well as the rate of force development [28]. They highlighted an increase in ankle and knee isometric muscle strength as well as in the rate of force development after anti-gravity training. Regarding spasticity, Noroozi et al [26] reported a decrease in intrinsic and reflex stiffness following anti-gravity training. The changes were greater than those observed in the control group. Finally, Aras et al [20] reported a significant improvement in the Gross Motor Function Measure (GMFM-66) after the different training modalities (AlterG, BWS and Lokomat) in both GMFM-D (standing section) and GMFM-E (walking-running section). However, there was no statistically significant difference between the groups in terms of GFMF-D and GMFM-E.

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3.5. Effect of anti-gravity treadmill training on balance

Several studies explored the effects of anti-gravity training on balance control in children with locomotor impairments [11,18,19,21–25,27,29–31]. The findings of those studies are summarized in Table 2. Balance assessments included center of pressure (CoP) measurements (i.e., CoP sway, CoP velocity, etc) during static (standing) [21,29], and dynamic balance assessment using center of mass and center of pressure displacements [18,19,23,25] as well as clinical tests such as the BESTest, the Berg Balance Score (BBS) or Timed Up and Go (TUG) [22,24,25,27,30,31]. All included studies reported improvements in balance following anti-gravity training. Moreover, six studies highlighted a greater improvement in balance compared to conventional therapies [11,18,19,21–23].

3.5. Effect of anti-gravity treadmill training on gait parameters

Gait related outcomes were commonly measured during overground walking and included spatiotemporal parameters (i.e., walking speed, stride length, step length, cadence, etc.) and endurance. Some studies reported a significant effect of anti-gravity training mainly on gait speed [11,20,22,24,25,27,28,31], step length [11,20,28], cadence [11,20] and walking endurance [20,24,25,31]. Regarding walking endurance, Aras et al [20] observed a significant improvement after all three training modalities (AlterG, BWS and robotic training). However, there was no statistically significant difference between the groups.

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Table 1. Results of methodological quality of articles using the PEDro score.

Studies	Study design	1	2	3	4	5	6	7	8	9	10	11	Total (/10)
Kurz et al **[16]**	Before/After	0	0	0	0	0	0	0	1	1	0	1	**3 (low)**
Emara **[21]**	RCT	1	1	1	1	0	0	0	1	1	1	1	**7 (high)**
Emara **[22]**	RCT	1	1	1	1	0	0	0	1	1	1	1	**7 (high)**
Birgani et al **[26]**	Case study	0	0	0	0	0	0	0	1	1	0	0	**2 (low)**
El-Shamy **[11]**	RCT	1	1	1	1	0	0	1	1	1	1	1	**8 (high)**
Rasooli et al **[27]**	Multiple case studies	0	0	0	0	0	0	0	1	1	0	0	**2 (low)**
Lotfian et al **[23]**	Multiple case studies	0	0	0	0	0	0	0	0	0	0	1	**1 (low)**
Azizi et al **[28]**	RCT	0	1	0	0	0	0	0	1	1	0	0	**3 (low)**
Azizi et al **[29]**	Multiple case studies	0	0	0	0	0	0	0	1	1	0	0	**2 (low)**
Azizi et al **[30]**	Multiple case studies	0	0	0	0	0	0	0	1	1	0	0	**2 (low)**
Dadashi et al **[31]**	Controlled cases study	0	0	0	0	0	0	0	1	1	0	0	**2 (low)**
Azizi et al **[15]**	RCT	0	1	0	1	0	0	0	0	0	1	1	**4 (low)**
Lotfian et al **[32]**	Before/After	0	0	0	0	0	0	0	0	0	0	1	**1 (low)**
Aras et al **[25]**	RCT	1	1	1	1	0	0	0	1	1	1	1	**7 (high)**
Noroozi et al **[24]**		0	0	0	0	0	0	0	0	0	0	1	**1 (low)**

NOTE. RCT: Randomized Controlled Trial; NECG: Nonequivalent Control-Group. The PEDro scale consists of 11 items: Item 1. eligibility criteria were specified. Item 2. subjects were randomly allocated to groups. Item 3. allocation was concealed. Item 4. the groups were similar at baseline regarding the most important prognostic indicators. Items 5, 6, and 7. there was blinding of all subjects, therapists, and assessors. Item 8. measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups. Item 9. all subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was analyzed by "intention-to-treat". Item 10. the results of between-group statistical comparisons are reported for at least one key outcome. Item 11 the study provides both point measures and measures of variability for at least one key outcome. Each item is scored as a "yes" or "no" and is worth 1 and 0 points respectively. The total score expressed on 10 points. The first item is not included in the sum of the total score of the PEDro scale.

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Table 2. Summary of participants characteristics and outcomes.

Study	Participant characteristics		Intervention		Outcomes of interest	ICF domains	Results
	Experimental group	**Control group**	**Anti-gravity training**	**Comparator training**			
Kruz et al [27]	9 children with CP	-	Anti-gravity training (2 participants continued conventional therapy)	-	Isometric muscle strength; spatiotemporal parameters; balance (BESTest)	Body function & activity	A significant improvement in the overall strength of the lower extremity, walking speed, time spent in the double support and the BESTest scores after anti-gravity training.
	(age = 8 to 18 yrs; GMFCS II - IV)						
Emara et al [18]	15 children with hemophilic knee arthritis	15 children with hemophilic knee arthritis	Anti-gravity training + stretching and strengthening exercise	Stretching and strengthening exercises	Concentric muscle strength (hamstrings and quadriceps); balance	Body function & activity	Peak torque of the quadriceps and peak torque of the hamstring increased in the control and anti-gravity group. Both groups demonstrated a significant increase in balance. Greater improvements were in favor of the anti-gravity group.
	Age = 8 to 11 yrs						
Emara et al [19]	15 spastic diplegic CP	15 spastic diplegic CP	Anti-gravity training + the same exercise program given to control group	Personalized therapeutic exercise program	Dynamic postural control (AP stability & M-L stability; overall stability /index)	Activity	A greater stability index was observed after anti-gravity training compared with the control group.
	Age = 6 to 8 yrs						
Birgani et al [29]	1 hemiplegic CP child	-	Anti-gravity training	-	Balance and postural stability based on the COP	Activity	The surface of COP signal decreased after training.
El-Shamy [11]	15 spastic diplegic CP	15 spastic diplegic CP	Anti-gravity & conventional therapy	Conventional physical therapy program	Gait spatiotemporal parameters, postural stability, fall risk	Activity	Anti-gravity group exhibited greater improvements in terms of spatiotemporal parameters, stability index and fall risk compared to the control group.
	Age = 8 to 12 yrs; GMFCS I-II						
Rasooli et al [21]	3 children with spastic hemiplegic CP	1 child with spastic hemiplegic CP	Anti-gravity training	Over-ground gait training	Postural stability (posturography)	Activity	The results of the posturography evaluations showed a consistent improvement in postural stability in both groups.
	Age = 6 to 12 yrs; GMFCS I-III						
Lotfian et al [28]	4 children with CP	-	Anti-gravity training	-			Ankle and knee isometric strength, RFD isokinetic strength increased after anti-gravity training. Ankle AROM increased

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	Age = 9 to 13 yrs, GMFCS II-III				Isometric strength, RFD, AROM, spatiotemporal gait parameters	Body function & activity	with training. Walking speed, step width and length increased after anti-gravity training.
Azizi et al [22]	3 children with spastic hemiplegic Age = 4 to 12 yrs	1 child with spastic hemiplegic	Anti-gravity training	OT focused on walking capacity.	Walking speed (10MWT) and dynamic balance (TUG)	Activity	The walking speed increased between 26 and 82 % after anti-gravity training, whereas it was limited to 35% for the control subject. The change in TUG was relatively small.
Azizi et al [30]	3 children with CP Age = 9 to 12 yrs	-	Anti-gravity training	-	Walking speed (10MWT), dynamic balance (TUG), endurance (6MWT)	Activity	All cases increased their walking speed, decreased the time recorded in TUG and increased the distance during 6MWT after anti-gravity training.
Azizi et al [31]	3 children with CP Age = 9 to 12 yrs	-	Anti-gravity training	-	Balance using the BBS and TUG	Activity	The time in TUG decreased up to 30% and Berg index increased up to 30% for all patients after anti-gravity training.
Dadashi et al [23]	2 children with hemiplegic CP Age = 4 to 14 yrs	2 children with hemiplegic CP	Anti-gravity training	OT focused on walking capacity.	Dynamic balance (center of mass and center of pressure displacements)	Activity	Dynamic balance improved after anti-gravity training. The changes were greater after antigravity training compared to control training.
Azizi et al [24]	9 children with CP Age = 4 to 15 yrs	5 children with CP	Anti-gravity training	OT focused on walking capacity.	Walking speed (10MWT), dynamic balance (TUG), endurance (6MWT)	Activity	Improvements in walking speed and endurance, measured by 10MWT and 6MWT, were statistically greater in anti-gravity than in control group.
Lotfian et al [25]	7 children with CP GMFCS = I-II	4 children with CP	Anti-gravity training	OT focused on walking capacity.	Gait spatiotemporal parameters, dynamic balance (COP and COM displacement), clinical measures (10MWT, TUG, 6MWT)	Activity	Walking speed, cadence and single support time increased by 98%, 10% and 65%. Clinical measures increased by 26% (10MWT), 18% (TUG) and 20% (6MWT) after anti-gravity training. Dynamic balance improved after anti-gravity training. All the changes were greater after antigravity training compared to control training.
Aras et al [20]	10 children with CP (one Withdrawn)	10 children with CP in robotic group and 10	Anti-gravity training	A group allocated for BWS treadmill training, and a	Gait spatiotemporal parameters, walking	Activity	Walking speed increased in the three groups but did not reach a statistical significance. After anti-gravity group, the increase in cadence, stride length, and stride time were statistically

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		children with CP in BWS training		Group allocated for robotic training	endurance (6MWT), GMFM-66		significant. The decrease in double support phase was statistically significant in the anti-gravity and robotic groups. The GFMF-D, GMFM-E and 6MWT increased in all the groups similarly.
	Age = 6 to 14 yrs; GMFCS II-III						
Noroozi etal [33]	9 children with hemiplegic CP (1 Withdrawn)	9 children with hemiplegic CP (1 Withdrawn)	Anti-gravity training	OT focused on walking capacity.	Ankle dorsiflexion spasticity by the assessment of reflex stiffness gain and intrinsic stiffness gain	Body function	Intrinsic stiffness gain and reflex stiffness gain parameters decreased substantially following anti-gravity training. The changes were greater than those observed in the control group.
	Age = 4 to 14 yrs						

Abbreviations: CP: Cerebral palsy, GMFCS: Gross Motor Function Classification System, OT: Occupational Therapy, BESTest: Balance Evaluation Systems Test, 10MWT: 10 m walking test, TUG: Timed up and go, 6MWT: Six-minute walking test; COP: Center of pressure; COM: Center of mass; AROM: Active range of motion, GMFM: Gross Motor Functional Measurement; AP: Anteroposterior, ML: Mediolateral, BWS: body weight support; RFD: rate of force development.

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Table 3. Summary of training parameters and settings.

Study	Training parameters	Anti-gravity treadmill settings
Kruz et al [27]	30 minutes per session, 2 times per week for 6 weeks	BWS was set to 40% of body weight, and gradually reduced to 10% by the end of the intervention. The speed of the treadmill was initially set at 90% of the child's over ground walking speed, and gradually increased.
Emara et al [18]	20 minutes per session, 3 times per week for 12 weeks	The BWS was set at 30% of the child's body weight The speed was set at 75% of over-ground speed and zero-degree inclination.
Emara et al [19]	20 minutes per session, 3 times per week for 12 weeks	Comfortable treadmill speed was selected for all participants as 75% of their comfortable speed during over-ground walking. The treadmill was set at 0-degree inclination.
Birgani et al [29]	45 minutes per session, 3 times per week for 8 weeks.	The training started with a 50% BWS and with a speed of 1.5km/h. Then, the BWS gradually reduced, and the speed increased based on the subject's ability.
El-Shamy [11]	20 minutes per session added to 1 hour of conventional therapy, 3 times per week for 12 weeks	The treadmill was set at 0-degree inclination. Comfortable treadmill speed was selected for all participants as 75% of their comfortable speed during over-ground walking. Verbal commands were given to the children to maintain upright posture
Rasooli et al [21]	45 minutes per session, 3 times per week for 8 weeks	Each session, training started with 50-70% of bodyweight support and 0.7-1.5km/h speed depending on the patients' condition and tolerance. After warm-up the bodyweight support decreased, and speed increased gradually based on the therapist's evaluation of the patients' tolerance.
Lotfian et al [28]	45 minutes per session, 3 times per week for 8 weeks	BWS was set at 50% and the speed was started in about 1 m/s. After a 3 to 4-minute warmup, the experienced trainer began to reduce the amount of the BWS and increase the speed and changed them during the training based on the patient's need.
Azizi et al [21]	45 minutes per session, 3 times per week for 8 weeks	**No information about anti-gravity treadmill settings.**
Azizi et al [30]	45 minutes per session, 3 times per week for 8 weeks	The inclination was set at 0°. The speed and BWS of the treadmill were set to their optimum level, which patients had their best gait pattern at
Azizi et al [31]	45 minutes per session, 3 times per week for 8 weeks	The inclination was set at 0°. These parameters were set to the levels in which the patient had the best walking pattern. The primary speed and BWS of each session were dependent on the condition of the patients and were set to 0.7-1.5km/h and 50-70% of the normal weight, respectively

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Dadashi et al [23]	45 minutes per session, 3 times per week for 8 weeks	At first, the BWS was set at 50% of the participant's weight, and the speed was about 1 m/s. As time passed, the speed increased, and the BWS gradually decreased
Azizi et al [24]	45 minutes per session, 3 times per week for 8 weeks	The treadmill was set at 0-degree inclination, the initial speed was set to 0.7 and the body weight support was selected according to gait patterns
Lotfian et al [25]	45 minutes per session, 3 times per week for 8 weeks	At the beginning of the training session, BWS was reduced by 50% and let him/her walk in a low speed to warm up. After 4-5 minutes, the BWS was gradually decreased while the speed was increased; the trainer adjusted these two parameters to help subject maintain a more accurate walking pattern
Aras et al [20]	45 minutes per session, 5 times per week for 4 weeks	BWS was started at 60% and gradually decreased to a level which prevented the collapse of the knee in flexion during the stance phase. The treadmill speed was initiated at the average walking speed according to the children's walking pattern, weight, and endurance, then, increased to the highest level tolerated.
Noroozi et al [33]	40 minutes per session, 3 times per week for 8 weeks	**No information about anti-gravity treadmill settings.**

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4. Discussion

This scoping review summarized the available literature on the effects of anti-gravity treadmill training on lower limb function and/or gait parameters in children with locomotor impairments. Overall, anti-gravity treadmill training brings some positive effects on lower limb function (i.e., strength and spasticity), balance and spatiotemporal gait parameters mainly in children with CP. Given the small number of RCT studies and the quality of the included studies, the result of this review shows that investigation of the effects of anti-gravity treadmill training for pediatric population with locomotor impairments is still at its early stage.

4.1. Anti-gravity training: protocols and settings

Overall, anti-gravity treadmill training is based on the principles of motor learning and neuroplasticity, through a mass practice and task-specific intervention that aims to promote long-lasting neuromuscular adaptation [32]. However, optimal training frequency and duration for gait rehabilitation with the anti-gravity treadmill remains unknown, due to the large variability between protocols in published studies. According to the recommendations of Verschuren et al., (2016), longer interventions with progressive intensities (e.g., duration: 8–16 weeks; frequency: 2 or 4 sessions/week) may be needed to experience meaningful motor function improvements in children with CP. Almost all the studies included in this review meet such recommendations. Regarding the progression in training settings, it has been suggested that, in order to get closer to the normative gait patterns, very low speeds and high levels of BWS should be avoided when possible [33,34]. Depending on the studies, the initial BWS levels were adjusted between 30 and 50%. The treadmill speed was set to 0.7-1.5km/h and gradually increased. However, the progression in these settings was poorly described. Moreover, no study reported individual data on settings progression. The disparate training schedules combined with the lack of information about settings adjustments limit our understanding of the impact of anti-gravity training on children with locomotor impairments and may preclude the clinical reproduction of the proposed protocols [35].

4.2. Effect of training on body functions

After anti-gravity treadmill training, a few studies reported an increase in lower extremity strength (as measured in isometric or isokinetic mode) [18,27,28], a decrease in spasticity [26], and improvement in gross motor function [20]. These improvements are relevant and need to be confirmed by further studies with larger sample size. Spasticity and a lack of muscle strength play a key role in gait impairment given the strong relationship between these parameters and walking ability in children with cerebral palsy [36–39]. Indeed, lower limb muscle strength explains approximately 21–47.8% of ambulatory capacity in these children [38,39]. Strength and spasticity might be considered to determine if a child with spastic cerebral palsy may benefit from an intervention to improve walking capacity.

4.3. Effect of anti-gravity training on activity

Compared to conventional therapy, five RCT studies [11,18,19,22,24] showed greater positive changes in balance and risk of falls after anti-gravity treadmill. These findings are particularly important for children with cerebral palsy, as they must control the postural instability caused by the decoupling they often have between the projection of their center of mass and center of pressure during gait [40]. As this physical impairment requires more energy for walking than in typically developing children [41], the acquisition of new locomotor capacities represents one of the primary objectives of these children.

Regarding gait parameters, several studies [11,20,22,24,25,27,28,31] highlighted an improvement in spatiotemporal parameters after anti-gravity treadmill training. In his RCT, El-Shamy [11] showed that the group who benefited from anti-gravity treadmill

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training exhibited a grater improvement in gait parameters (i.e., walking speed, stride length, cadence and double support time) compared to control. Despite the promising effects reported in this last study, the combination of anti-gravity training with a physical therapy program in the experimental groups limits the ability to isolate the contribution of the antigravity treadmill training alone. Recently, Aras et al [20] investigated the effect of anti-gravity training (AlterG) in comparison to other modalities which are traditional BWS treadmill training and robotic assisted treadmill training (Lokomat). Despite the presence of a trend, the authors did not observe significant change in walking speed after the three training modalities. However, in the anti-gravity group, the increase in cadence, stride length, and stride time were statistically significant, while the increases in those parameters was not significant in the robotic and BWS groups. In these RCTs studies, the authors did not compare change scores to establish differences between groups, but rather compared beginning and end values. In our opinion, this is a statistical limitation and might have influenced the results. Moreover, most of the selected outcome measures are known to be associated to walking speed [11,20,22,24,25,27,28,31]. Consequently, an increase in walking speed induces inherently an improvement in the majority of these outcomes. Unfortunately, the studies only concentrated on these spatiotemporal aspects and did not present other biomechanical parameters. However, to understand the different strategies used by children in gait production, it is important to enrich the overall biomechanical data by considering other factors such as joint kinematics and kinetics as we EMG data.

In pediatric, the findings in the current literature on anti-gravity training modality show some promising benefits (i.e., balance and spatiotemporal parameters) specifically in children and adolescents with cerebral palsy. However, given the disparity of results and the variable quality of the studies conducted to date, more studies are needed to document effectiveness compared to conventional approaches before clinical implementation can be recommended or not. In future studies, the implementation of personalized and well-designed protocols for anti-gravity training is needed to get a better understanding of how this modality could be applied in heterogenous populations of children with locomotor impairments. Moreover, additional information about the patient's gait performance during daily life, as a complement to laboratory-based assessments, could improve the understanding of the patient's overall gait difficulties, enhancing clinical care.

5. Conclusions

Our analysis of the literature showed a low level of evidence for employing anti-gravity treadmill training to improve gait ability in children with locomotor impairments. Well-designed, high-quality clinical trials that complement clinical data with objective, quantitative gait data is needed to provide more detailed information on the potential effects of anti-gravity training in general, as well as on its specific impact on gait movement patterns. Finally, studies are needed to investigate the differences between a lower body positive pressure-based and a harness-based bodyweight supported system and their specific influence on gait parameters.

Supplementary Materials: The following are available online at www.mdpi.com/xxx/s1, Table S1: Search terms

Author Contributions: **YC** developed the search strategy and the assessment framework for this review which have been validated by a science librarian and **CM**. **YC and LPG** screened the search hits for eligibility and rated studies' quality. **YC** extracted as well as synthesized the relevant data and wrote the first draft of the manuscript. **CM** and **LB** did a major revision of the manuscript. All authors read and approved the final manuscript.

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