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Effects of a lower extremity exercise program on gait biomechanics and clinical outcomes in children and adolescents with obesity: A randomized controlled trial

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ABSTRACT

Background: Research highlights the detrimental effects of obesity on gait biomechanics and the accompanied risk of lower-extremity skeletal malalignments, increased joint stress, pain and discomfort. Individuals with obesity typically show increased knee valgus angles combined with an increased step width. Accompanying muscular dysfunctions impede their ability to compensate for these alterations, especially in the frontal plane. To date, no studies are available, which evaluated the potential effects of an exercise program (EP) in reducing these unfavorable biomechanical changes.

Research questions: Is a 12-week EP, which includes hip abductor and knee extensor strength exercises and fosters dynamic knee alignment, effective in positively altering gait biomechanics in children and adolescents with obesity?

Methods: This study was a randomized controlled trial having children and adolescents with obesity assigned to an EP (n = 19) or control (n = 16) group. Pain, self-rated knee function, muscle strength and 3D gait analysis during walking and stair climbing were evaluated.

Results: Results indicate that the EP was able to increase muscular strength especially in the hip abductors. In addition, children from the EP group walked with less maximum hip adduction and reduced pelvic drop during weight acceptance at follow-up. No changes were present in self-rated knee function, pain or discomfort.

Significance: Even though effects were small, results indicate that an EP is an effective short-term possibility to counteract the progressive development of biomechanical malalignments of the lower extremity. Clinical parameters indicated that the program was feasible. Nonetheless, low adherence highlights the need to develop more attractive programs.

Clinical Trials Reg. No: clinicaltrials.gov (NCT02545764).

1. Introduction

Worldwide obesity has nearly tripled in the last three decades resulting in approximately 340 million children and adolescents being overweight or obese [1]. For the United States, obesity accounts already for more than 12 million children and adolescents [2,3]. Similar trends are evident in Europe. According to the Austrian Federal Ministry of Health, in 2012 almost 17% of all children were overweight and 7% were obese and prevalence is still increasing [4]. These facts place overweight and obesity as one of the most critical and accelerating global health issues.

Next to the commonly linked health risks of obesity and overweight [5], there is a substantial body of literature highlighting accompanying negative biomechanical changes [6–10]. Most of the studies suggest that these changes result in an increased risk of developing unfavorable gait patterns and lower-extremity skeletal malalignments such as

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increased knee valgus angles, combined with an increased step width [11]. Gushue et al. [11] concluded that while overweight children may develop a gait adaption to maintain similar sagittal movement patterns, they are unable to compensate for alterations especially in the frontal plane. Combined with high body mass and a reduced muscular function, these altered gait patterns and malalignments are expected to increase joint stress and articular cartilage damage [9,12]. This in return leads to reduced physical activity due to accompanying pain and discomfort [13].

Physical activity is an important factor to reduce body mass. Exercise programs (EP), which aim at strengthening knee extensors and hip abductors and foster control of the lower-limb alignment during dynamic loading conditions, might help to reduce the increased stress, pain and perceived discomfort. Consequently, this might support children in regaining a more physical active life style. Increased muscular joint stabilization, might even slow down an ongoing deterioration in skeletal malalignments or reduce the risk of developing osteoarthritis or similar joint diseases over the long-term.

To date, however, there is no scientific literature available, which examined the potential effects of such an EP, especially from a biomechanical point of view. Such studies are urgently needed as they could provide a scientific basis of negotiation for implementing such programs in health care systems and to justify their financing against social security funds.

Accordingly, we conducted a randomized controlled trial, which pursued two main goals. The first goal was to evaluate an EP that combines strength and neuromuscular exercises from a knee health and muscle strength perspective. The second goal was to examine the effectiveness of such a program in increasing dynamic control of the frontal knee and hip alignment during weight-bearing conditions such as walking and stair climbing [10]. We hypothesized that such a program will improve muscle strength, joint function, and the ability to control the knee and hip frontal plane kinematics.

2. Methods

2.1. Study design

This study was a single blinded, randomized controlled trial with outcomes assessed at baseline and after a 12-week follow-up. Details on the study protocol were previously published [14]. Parents and their children were informed prior to the study and written informed consent was obtained. The study was approved by the local Ethics-Committee (EC Nr: 1445/2013) and registered at clinicaltrials.gov (NCT02545764).

2.2. Participant recruitment and allocation

Children and adolescents aged between 10 and 18 years, with an aged-based body mass index (BMI) above the 97th percentile were included in this study [15]. Exclusion criteria were: (i) syndromes associated with obesity (e.g. Prader-Willi syndrome); (ii) chronic joint diseases; (iii) neuro-motor diseases; and (iv) any history of a lower extremity joint surgery.

Participants were recruited between September 2015 to May 2017. Fig. 1 shows the participant flow through the trial. Group allocation was performed by using computer-generated random numbers, consecutively numbered, sealed, and opaque envelopes. Out of 103 participants screened, 52 (51%) were ineligible or did not wish to participate. The other 51 participants were randomized to the EP group (n = 26) and control group (n = 25). From those, 20 individuals started the EP. Their mean (standard deviation) percentage of completed exercise sessions was 51.9% (25.0). Two participants discontinued due to self-reported lack of time after the second exercise session. When excluding these, adherence increased to 56.7% (21.4) with a range of 26.1–86.4%.

During different stages of the study, some participants refused their further participation. Due to marker occlusion, data of some participants had to be excluded from the analysis. In addition, some participants missed to complete the KOOS. This resulted in different group sizes per outcome and is illustrated in Fig. 1.

2.3. Intervention

The protocol for the strength and neuromuscular EP was described in the trial protocol [14] and will only be reported briefly here. The program was performed as a progressive group training twice a week over a 12-week period. Each session lasted 60 min. A physical therapist supervised the program, which consisted of a warming up, strength exercises for the knee and hip muscles and neuromuscular exercises for the lower extremity and core muscles. The main intention of that program was to increase the children's ability to maintain a controlled lower-extremity alignment during loading conditions such as single support during walking and stair climbing. Quadriceps strength training involved non-weight bearing and weight bearing exercises [16,17]. The hip muscle strengthening was in accordance to the program of Bennell et al. [18]. The intensity of the exercises were monitored continuously and adjusted to the self-perceived level of effort (based on the RPE CR-10) for each participant throughout the program [19]. The control group received no exercise program but was able to participate afterwards.

2.4. Outcomes

The Knee Injury and Osteoarthritis Outcome Score (KOOS, Austrian-German version) questionnaire was used to assess the participants' rating about their knee problems [20]. KOOS consists of five subscales: (i) knee pain; (ii) other symptoms; (iii) function in daily living (ADL); (iv) function in sport and recreation (Sport/Rec.); and (v) knee related quality of life (QOL).

An orthopedic clinical examination with focus on lower-extremity alignment, range of motion, and muscle function was conducted by a trained clinician at baseline and follow-up. Varus/valgus knee position was determined by visual inspection during standing. Changes in strength of the quadriceps and hip abductor muscle groups were assessed with isometric manual muscle function tests by using a handheld dynamometer (MicroFET 2, Hoggan health industries, Draper, UT, USA). Each test was repeated four times and the mean was used for analysis. Data were normalized to body mass (N/kg). If assessors are well trained these tests provide good levels of inter- and intra-session reliability [21]. Anthropometric and body composition variables were assessed using conventional anthropometry and bioimpedance analysis in a standardized manner and at the same time of the day at baseline and follow-up (BC-418 MA, Tanita Co., Japan).

Information on amount of participated training sessions, adverse events, and average overall pain (on a five-point scale) during and after each exercise session were collected using a day-by-day exercise logbook.

An eight-camera motion capture system (MX-series, Vicon, Oxford, UK) operating at 150 Hz and two force plates (Kistler, Winterthur, CH) sampled at 1000 Hz each were used to conduct standard clinical 3D gait analysis (3DGA). The Cleveland Clinic marker set was used as a kinematic model, and the regression equation from Davis et al. was used to determine the hip joint center [22]. 3DGA was performed barefoot for two conditions: walking on a 12 m walkway and across an instrumented staircase. The order of the test conditions was always randomized. For the walking condition, speed was self-selected during baseline and controlled by the boundaries of ± 5% of baseline speed during follow-up. For stair ascent and descent, participants walked with a cadence of approximately 110 steps per minute assisted by a metronome [10]. The staircase was 80 cm wide, had three steps and a platform at the top. Each step was 16 cm high and 30 cm deep. Kinematic data were

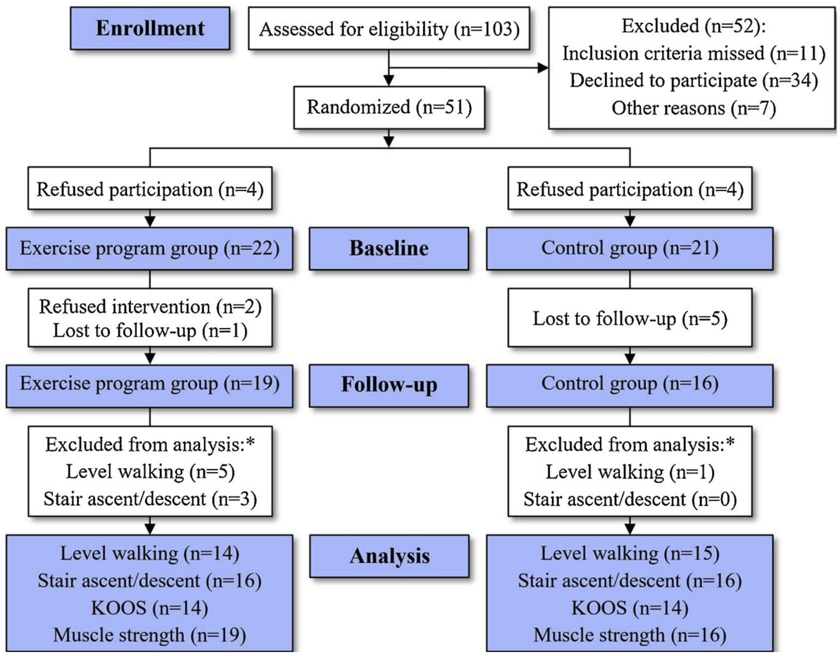

Fig. 1. Flow-chart of the participant flow during the entire study. Due to several reasons data of some participants were excluded at the end of the study. This resulted in different sample sizes for the different outcome variable categories.

analyzed beginning with initial contact at the first step for ascent and descent. For each participant and condition, five trials were recorded out of which the most representative trial was identified using the method by Sangeux and Polak [23]. Data were time-normalized to 100% gait cycle (gc). Several discrete variables during stance were obtained from the 3DGA (walking and stair ascent/descent); for the pelvis: mean anterior tilt; maximum drop and elevation; mean rotation; for the hip: maximum, minimum, and ROM for all three planes; for the knee: flexion at initial contact and maximum flexion between initial contact and 30% gc, as well as maximum, minimum, and ROM for the frontal and transversal planes; for spatio-temporal parameters: walking speed, cadence, step length/width, and single/double support.

It was not possible to blind participants or the physical therapist supervising the training program. However, the movement scientist conducting the 3DGA and the muscle testing were blinded.

2.5. Statistical analysis

Basic features of the data were summarized using descriptive statistics. Means and standard deviations were used to describe the data. Assumption of normality was checked by using a Shapiro-Wilk test. Data were processed in Matlab (The MathWorks Inc., Natick, MA, USA). Statistical analysis was conducted using IBM SPSS Statistics 24 (IBM Corporation, NY, USA). The level of significance was set a priori to 0.05 for all analyses. All analyses were performed on a randomly chosen body side per participant using computer generated numbers. Baseline characteristics between both groups were similar, except for gender ($\chi^2(1) = 3.976$, $p = 0.046$), see Table 1. Additional independent pairwise comparisons did not indicate any differences in our outcome variables between males and females at baseline. Therefore, gender was not considered as a covariate during statistical analysis. The intraclass correlation (ICC), defined as the ratio of the between-subject variation to the total variation (both derived from a repeated measures analysis of variances, ANOVA), was used to assess the consistency of the four strength measurements per muscle and test session [24]. Results indicated good intra-session reliability (ICC > 0.95).

All statistical analyses followed a two-level approach. In a first-level, all participants who started the EP were included (intention to treat analysis, ITT). ITT analysis limits inferences based on arbitrary subgroups, reflects the practical clinical scenario, maintains prognostic balance, and thus provides a more unbiased estimate of treatment effects [25]. In accordance with Gupta et al. [25], a second-level per protocol analysis (PP) was also conducted including only those who, at least, participated in 60% of the EP sessions. Supportive PP analysis more strictly analyze potential intervention effects and assist in reducing type II errors. However, PP analysis was only performed when a minimum sample size of ten was available.

For the first-level analysis, a 2-way mixed ANOVA with repeated measures (time: pre and post) and group as an between-subject factor (EP group, control group) was applied to the discrete outcome variables (anthropometrics, KOOS, strength, and 3DGA) to identify any interactions of time × group or main effects in the selected outcomes. Second-level PP analyses were performed using Wilcoxon signed rank tests for both groups separately.

Additionally, in order to identify any global gait pattern changes, the entire kinematic waveforms from the 3DGA between baseline and follow-up were also submitted to a *t*-test or Wilcoxon signed rank test (depending on the normality assumption) from the SPM1D package available for Matlab (v.0.4, http://www.spm1d.org). SPM1D is a statistical parameter mapping tool using the random field theory and basically allows to conduct conventional statistical tests on entire waveform sets. Details about it were published by Pataky et al. [26].

3. Results

3.1. Exercise-log, pain, KOOS, and body composition

The grand mean of the self-rated pain (on a scale from 1 to 5) across all participants was 1.0 (0.06) before and 1.0 (0.04) after the exercise sessions. Two participants occasionally reported knee pain between 2–4. In most of these cases pain was reduced after the EP session. The ITT ANOVA did not reveal any significant interactions or main effects in any of the KOOS subscales. The additional PP analysis using Wilcoxon signed rank tests confirmed these results. KOOS baseline results are presented in Table 1. The ITT ANOVA indicated a significant increase in fat free mass only, but no interaction effect of time × group (see Table 2). The PP analysis supported this result.

Table 1
Baseline characteristics of those, who participated at baseline and follow-up assessments. Data are reported as mean (SD), unless otherwise stated.

Baseline characteristics	EP (n = 19)	Control (n = 18)	*p*-value*
Age (yrs.)	13.2 (2.2)	13.3 (2.3)	0.873
Sex (m/f), n (%)	m: 10 (52.6) f: 9 (47.7)	m: 15 (83.3) f: 3 (16.7)	**0.046**
Height (cm)	162.8 (10.3)	165.3 (12.4)	0.843
Body mass (kg)	94.4 (31.3)	92.3 (21.9)	0.816
BMI (kg/m^2)	34.8 (8.2)	33.3 (4.6)	0.843
Dominant side, n (%)	r: 16 (84.2) l: 2 (10.5) missing: 1 (5.3)	r: 15 (83.3) l:3 (16.7)	0.630
Knee varus/valgus, n (%)	varus: 0 (0) valgus: 14 (73.7) normal: 5 (26.3)	varus: 0 (0) valgus: 15 (83.3) normal: 3 (16.7)	0.476
Pes planus/neutral, n (%)	pes planus: 14 (73.7) neutral: 5 (26.3)	pes planus: 15 (83.3) neutral: 3 (16.7)	0.476
Body fat (%)	41.3 (7.5)	39.7 (7.7)	0.531
Fat mass (kg)	40.8 (21.2)	36.6 (10.9)	0.964
Fat free mass (kg)	53.6 (12.0)	55.7 (15.9)	0.879
KOOS - knee pain	81.7 (23.9)	85.3 (19.7)	0.986
KOOS - other symptoms	82.3 (18.6)	84.1 (16.3)	0.946
KOOS -ADL	89.0 (16.4)	91.4 (13.2)	0.710
KOOS - Sport/Rec.	81.5 (22.1)	83.3 (24.5)	0.573
KOOS - QOL	87.8 (17.2)	86.0 (16.6)	0.689

Significant results are highlighted bold.
* Independent *t*-test or Mann-Whitney U test (depending on normality of data); for gender, dominant leg, knee and foot status a Pearson Chi-Square test was used.

3.2. Muscle strength

The ITT ANOVA did not reveal any significant interactions or main effects in strength outcomes. However, the additional PP analysis using a Wilcoxon signed rank test indicated a significant increase of the hip abductor strength from baseline to follow-up in the EP group. A change in quadriceps strength slightly failed to reach significance. There were no significant changes present in the control group. Details for both groups are presented in Fig. 2.

3.3. 3D gait analysis

For the 3DGA, the ITT ANOVA indicated several significant interaction effects of time × group and some main effects of time only for the discrete kinematic variables (Fig. 3 and Table 2). For simplicity, only the significant results are presented in Table 2. Spatio-temporal parameters did not change from baseline to follow-up in any group. Due to partly low numbers (n < 10) in groups, no statistical PP analysis were conducted for the kinematics.

The SPM1D analysis confirmed the changes in pelvis elevation and hip maximum adduction during stance (see Fig. 4). No other relevant changes were present for the walking and stair ascent/descent conditions between baseline and follow-up.

4. Discussion

Overweight children and adolescents commonly experience increased knee valgus angles and a greater step width combined with muscular dysfunctions [11]. These unfavorable gait patterns and lower-extremity malalignments place them at risks of increased joint stress, pain and discomfort [6,9,10,12]. There is plenty of research available evaluating weight loss programs and functional effects of aerobic exercises and different forms of various EP [27]. However, none of these studies focused on the potential effects of an EP in reducing these unfavorable gait patterns using 3D gait analysis techniques. Accordingly, our primary aim was (1) to evaluate an EP that combines strength and

Table 2
Results of the main effects and interaction effects from the ITT ANOVA, corresponding pairwise differences (baseline – follow-up) and their 95% confidence intervals (CI).

Differences (baseline – follow-up)	EP			Control			ANOVA (group × time)			
	Mean (SD)	95%CI		Mean (SD)	95%CI		*df*	*F*	*p-values*	*partial* η^2
Body composition										
Fat free mass (kg)	−0.8 (2.9)	−2.2	0.7	−1.9 (3.4)	−3.6	−0.3	(1,35)	6.771	0.013	0.162
Walk										
Pelvis max. elevation (°)	1.3 (1.7)	0.3	2.2	−0.9 (2.7)	−2.4	0.6	(1,27)	6.392	0.018	0.191
Hip max. add. during stance (°)	2.2 (1.9)	1.1	3.3	−0.5 (2.9)	−2.2	1.1	(1,27)	8.840	0.006	0.247
Max. knee flex. initial contact (°)	2.6 (4.6)	−0.1	5.3	−0.9 (4.4)	−3.3	1.6	(1,27)	4.188	0.051	0.134
Stair descent										
Pelvis max. elevation (°)	1.2 (2.3)	−0.05	2.4	−0.6 (2.0)	−1.6	0.5	(1,30)	5.398	0.027	0.152
Hip abd./add. ROM during stance (°)	1.5 (3.4)	−0.3	3.3	−2.4 (5.1)	−5.1	0.3	(1,30)	6.464	0.016	0.177
Hip max. add. during stance (°)	2.4 (3.2)	0.7	4.1	−1.1 (3.1)	−2.7	0.6	(1,30)	9.608	0.004	0.243
Max. knee flex. initial contact (°)	2.0 (4.8)	−0.5	4.6	−1.9 (5.7)	−4.8	1.2	(1,30)	4.400	0.044	0.128
							ANOVA (time)			
							df	F	p-values	*partial* η^2
Walk										
Pelvis max. drop (°)	−1.0 (1.6)	−1.9	−0.1	−1.3 (2.6)	−2.7	0.2	(1,27)	7.885	0.009	0.226
Hip abd./add. ROM during stance (°)	2.6 (1.9)	1.4	3.7	0.9 (4.3)	−1.5	3.3	(1,27)	7.484	0.011	0.217
Stair ascent										
Knee abd./add. ROM during stance (°)	1.9 (5.7)	−1.1	5	3.2 (6.8)	−0.4	6.9	(1,30)	5.281	0.029	0.15

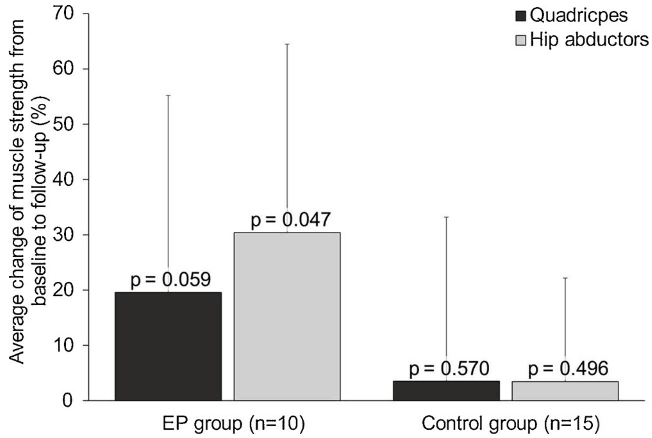

Fig. 2. Per protocol (PP) analysis of the change in isometric muscle strength from baseline to follow-up. A significant difference was only present for the hip abductors. Quadriceps failed to reach significance.

neuromuscular exercises for the lower extremity from a knee health and muscle strength perspective, and (2) to examine its effectiveness in increasing dynamic control of the frontal plane kinematics, especially at the hip and knee level, during walking and stair ascent/descent.

Our results indicate that the EP was able to modify biomechanical gait patterns at the pelvic and hip level and thus partly support our hypothesis. In detail, the children from the EP group walked with less maximum hip adduction and reduced pelvic contralateral drop during weight acceptance. This could be interpreted as an increased neuromuscular control of the knee joint to counteract a medial knee collapse during dynamic weight-bearing and a better stabilization of the pelvic motion. In an earlier study we analyzed the test-retest reliability error-margins of 3DGA in a similar population [28]. Our observed effects are only slightly above those thresholds. From a clinical point of view, a change of approximately 2° seems also rather irrelevant. However, the intervention period only lasted for 12 weeks with two sessions per week and, in general adherence was low. Nonetheless, the kinematic effects were accompanied by a reasonably increased hip abductor (+30%) strength. The quadriceps strength (+%20) failed to reach significance. When strength data were analyzed without normalization, both muscles turned out to be significantly increased. This could indicate that normalization to body mass was not optimal and might has masked relevant changes. Nonetheless, it seems very plausible that the increased strength has equipped participants with a better muscular control to counteract a medial knee collapse during weight acceptance and to increase the frontal control of their pelvic motion. However, results were only present for the level walking and the stair descent condition. Interestingly, no effects were seen in the stair ascent condition. We do not have a clear answer to this inconsistency. Either, the potential effects in our data were masked due to low power or small effect sizes, or children may have faced a more challenging situation during stair ascent and the increased strength and regained muscular control was not sufficient to compensate during this situation. Regarding the body composition variables, only the fat free mass showed a significant increase. However, this was the case for both groups and can be attributed to physical growth.

Even though effects in general were rather small (and partly only evident in the PP analysis), our results at least might indicate that an EP is able to foster a better control of the frontal femoral alignment and pelvic obliquity during the weight-bearing phase of locomotion. When adherence rates, training intensities, and EP duration are increased, these changes might even grow to more clinically relevant effects (˜5°) [29]. Future studies should account for this and should also include joint kinetics and musculoskeletal modelling to analyze the potential effects on joint loading as well. If our results point in the right direction, this could prove that a hip abductor and knee extensor neuromuscular strength program is an effective short-term possibility to counteract the progressive development of biomechanical malalignments of the lower extremity. Future studies should also obtain lower-extremity radiographic information to determine knee valgus angles and skeletal age. In case of a knee valgus below a surgical intervention threshold (e.g. for hemiepiphysiodesis) and that growth is not completed, it might be possible that an intervention program is more effective in changing gait parameters compared to participants were structural deformities are already manifested.

Pain and discomfort are major factors preventing individuals with overweight or obesity to regularly perform physical activities [30]. Increasing physical activity is an important cornerstone in the management of overweight and obesity. In this study we have used the KOOS questionnaire and a day-by-day exercise log to assess knee health from a pain and discomfort point of view. Our results did not indicate any change in these outcomes. However, our sample comprised individuals without any joint disorders such as knee osteoarthritis. Thus, knee health was relatively high at baseline and almost similar to their normal-weight counterparts [31]. Nonetheless, these results at least indicate that the intensity of the training program did not cause more pain or provoked other clinical symptoms like a reduction in knee function or an increase of joint problems. If our results prove to be true, such programs could be an effective measure to increase the participation of these individuals in regular physical activities.

The observed adherence was rather low with an average of 57% of attended sessions over the course of the 12 weeks. It is almost surprising that these low exercise intensities were sufficient to demonstrate biomechanical changes in gait patterns. However, these children and adolescents are a highly inactive population [32]. Therefore, the results of the present study might suggest that even such low exercise intensities can induce positive adaptions to muscle strength in this group. However, the low adherence indicates that the EP itself was probably not optimally developed to the requirements of this population and needs adjustment. Recently, Lee et al. examined the feasibility of a 4-week low-volume high intensity training (HIT) for individuals with overweight or obesity and found that the majority of participants enjoyed the HIT and that more than half of the participants (58%) reported that the HIT is a more enjoyable form of training than other types of exercises [33]. Therefore, future investigations may opt to combine the HIT and our program as this might be a purposeful solution.

The results of this study have some limitations. During the planning of this study, joint kinetics were included as outcomes. However, technical issues prevented us from using those for analysis. Therefore, this study only reported kinematic effects. Recently, two studies demonstrated a clinically relevant decrease in joint loading for pure weight-loss programs [34, 35]. It would be interesting to see if an EP is able to reduce joint loading as well. This would also raise the question if such a program can reduce the risk of developing osteoarthritis or similar joint diseases over the long-term. This study used a traditional marker set. To date, there are obesity specific marker sets available, which might perform better from an accuracy perspective [36]. The dimension of our staircase is in accordance with the Austrian building regulation from 2007. Future studies might implement the latest regulations. Lastly, the sample size of 48 participants, including 20% dropouts, was originally estimated based on kinetic outcomes. In consequence, it might not be perfectly applicable for our results.

5. Conclusion

Even though effects were small the EP might be an effective short-term possibility to counteract the progressive development of biomechanical malalignments of the lower extremity. In addition, the knee health outcomes indicate that the EP did not cause more pain or induced any other clinical symptoms and thus, proves feasibility. Nonetheless, adherence itself was rather low and highlights the need to

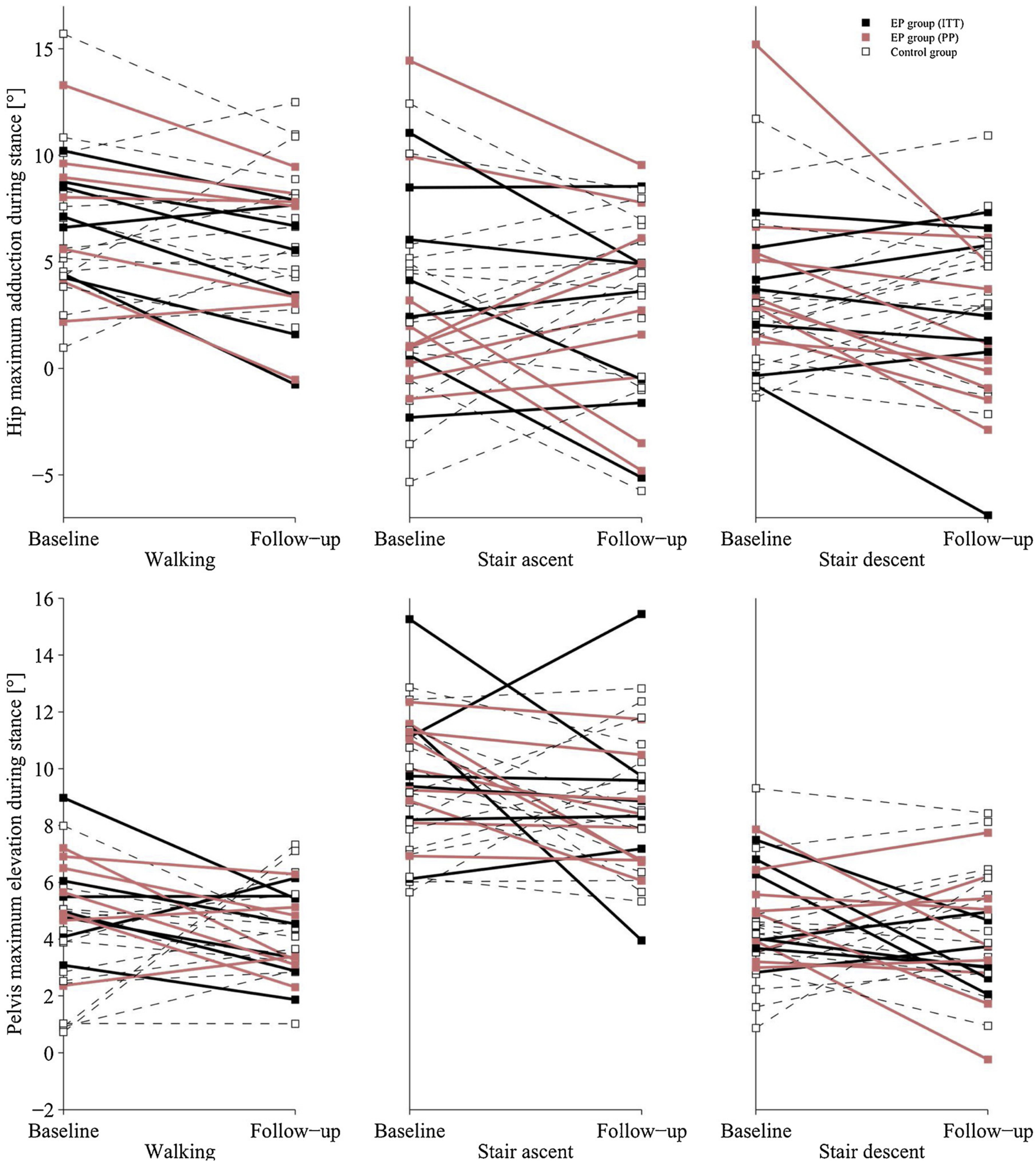

Fig. 3. Inter-individual change of the maximum pelvis elevation and hip adduction during stance from baseline to 12-weeks follow-up for all three walking conditions. Values are displayed for each participant from the EP group (black bold lines), only from those who at least participated in 60% of the EP session (bold colored), and for the control group (dashed lines).

develop more attractive programs for this group.

CRediT author statement

B. Horsak: Conceptualization, Methodology, Software, Formal Analysis, Writing – Review & Editing, Project Administration, Funding Acquisition. C. Schwab: Methodology, Software, Verification, Formal Analysis, Visualization. A. Baca: Resources, Writing – Review & Editing, Supervision. S. Greber-Platzer: Resources, Writing – Review & Editing, Supervision. A. Kreissl: Data Curation, Formal Analysis, Writing – Review & Editing. S. Nehrer: Writing – Review & Editing, Supervision. M. Keilani: Writing – Review & Editing, Supervision. R. Crevenna: Resources, Writing – Review & Editing, Supervision. A. Kranzl: Resources, Programming, Writing – Review & Editing, Supervision. B. Wondrasch: Conceptualization, Methodology, Funding Acquisition, Writing – Review & Editing.

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Conflicts of interest

There is no conflict of interest to declare.

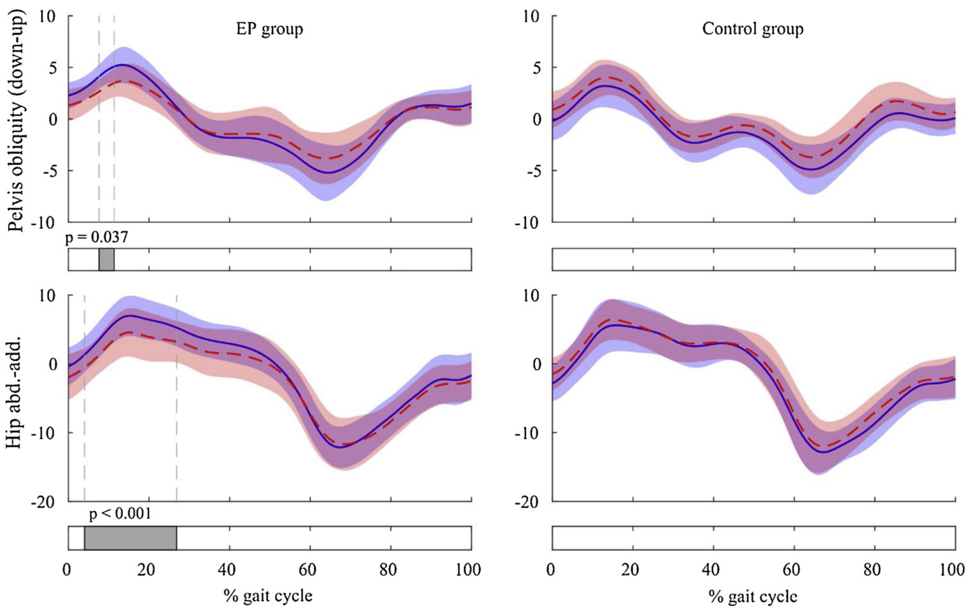

Fig. 4. Results of the SPM1D-analysis for pairwise comparisons between baseline (blue, solid line) and follow-up (red, dashed line) for the EP group (left) and the control group (right). Data show the pelvis drop and elevation and hip abduction/adduction kinematics (mean and SD). Black bars indicate significant differences between baseline and follow-up, where the SPM{t} values exceeded the alpha level threshold of 0.05. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.).

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.gaitpost.2019.02.032.

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