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Effects of the EXECP Intervention on Motor Function, Muscle Strength, and Joint Flexibility in Individuals with Cerebral Palsy

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ABSTRACT

VALADÃO, P., F. CENNI, H. PIITULAINEN, J. AVELA, and T. FINNI. Effects of the EXECP Intervention on Motor Function, Muscle Strength, and Joint Flexibility in Individuals with Cerebral Palsy. *Med. Sci. Sports Exerc.*, Vol. 56, No. 1, pp. 1–12, 2024. **Purpose:** Numerous exercise interventions to enhance motor function in cerebral palsy (CP) have been proposed, with varying degrees of effectiveness. Because motor function requires a combination of muscle strength, joint flexibility, and motor coordination, we designed a supervised multicomponent exercise intervention (EXErcise for Cerebral Palsy, or EXECP) for individuals with CP. Our aim was to evaluate the effects of the EXECP intervention and its retention after it ceased. **Methods:** The EXECP intervention combined strength training for the lower limbs and trunk muscles, passive stretching for the lower limb muscles, and inclined treadmill gait training. Eighteen participants with CP (mean age, 14 yr; 13 were male) were tested twice before the 3-month intervention and twice after the intervention, each test separated by 3 months. Seventeen typically developing age- and sex-matched controls were tested twice. Motor function was assessed with the 6-min walking test (6MWT) and the gross motor function measure dimensions D and E. Passive joint flexibility was measured with goniometry. Isometric and concentric muscle strength were assessed at the knee, ankle, and trunk joints. **Results:** The EXECP intervention successfully increased 6MWT ($P < 0.001$), gross motor function measure ($P = 0.004$), and muscle strength for knee and trunk muscles ($P < 0.05$), although no changes were observed for ankle joint muscles. Hip and knee joint flexibility also increased ($P < 0.05$). After the retention period, all tested variables except the 6MWT and knee joint flexibility regressed and were not different from the pretests. **Conclusions:** The improvements in strength, flexibility, and possibly motor coordination brought by the EXECP intervention were transferred to significant functional gains. The regression toward baseline after the intervention highlights that training must be a lifelong decision for individuals with CP. **Key Words:** CHILDREN, YOUNG ADULTS, TRAINING, REHABILITATION, WALKING

Cerebral palsy (CP) is a neurodevelopmental condition caused by a lesion in the developing fetal or infant brain. During development, the lesion leads to secondary symptoms such as muscle weakness, reduced joint flexibility, and incoordination (1–4), which hinder motor function for everyday activities such as walking and climbing stairs (5–7). Furthermore, these secondary symptoms may induce lower physical activity level (8,9) and cardiometabolic performance (5), increasing the risk of chronic diseases such as cardiovascular problems (10,11). Thus, there is an urgent need for therapeutic interventions capable of breaking this downward spiral of inactivity and loss of function.

Strength training is among the most studied interventions in CP, and it is effective if the established training guidelines (11–13) are followed (14–21). Although successful in increasing muscle strength, some interventions failed (15,17–20), whereas others succeeded in improving motor function (14,17). The diverging results in motor function gains induced by exercise interventions seem to arise from three main reasons. First, the neural and morphological adaptations are highly specific to the strength training methods (17,22), which varied in these studies. Second, functional tasks involve a

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complex interaction between muscle strength, joint flexibility (i.e., maximum passive joint range of motion (ROM)), and motor coordination. Lastly, functional tasks involve activation of several muscle groups spanning across multiple joints. Thus, an adequate intervention should train all relevant muscles with naturalistic patterns of neural activation.

Despite the broad use of stretching to prevent or alleviate loss of joint flexibility in CP, its efficacy is unclear (4,23,24). Longitudinal studies applying manual passive stretching therapies for 6–9 wk have typically reported an increase in joint ROM with no mechanical changes (e.g., resting fascicle length), suggesting that increased stretch tolerance played a major role in the ROM increase (25–28). Little is known about the effects of more prolonged stretching interventions (28), and it is possible that structural changes (e.g., sarcomerogenesis) require more time. It may also be that combined training is more effective. Kalkman et al. (26) demonstrated that combined ankle plantarflexors strength training and passive static stretching for children with CP was more effective in increasing resting fascicle length than solely stretching. The mechanistic explanation is that strength training increased tendon stiffness, decreasing the relative muscle stiffness, and thus increasing the stretch taken by the muscle and decreasing the stretch taken by the tendon.

Gait training has been shown to be safe, feasible, and able to improve walking ability in children and young adults with CP (29). The inclined treadmill setup seems particularly effective, as it requires a greater ankle dorsiflexion (DF) in the swing phase and serves as a stretch for the ankle plantarflexors in the stance phase (30,31). Daily gait training with an inclined treadmill has been demonstrated to increase walking speed, DF strength, and active ROM, and reduce ankle stiffness in only 4–6 wk (32,33). Walking ability and overall gross motor function are usually measured both in research and clinical evaluation using the 6-min walking test (6MWT) and the gross motor function measure (GMFM; (34)), and both have been shown reliable in people with CP (35–37).

Our EXErcise for Cerebral Palsy (EXECP; Valadão et al. (38)) intervention was conceived to address some of the aforementioned limitations, combining three training modes: 1) strength training for the main lower limb and trunk muscles, using both mono and multiarticular exercises; 2) flexibility training for diagnosed short lower limb muscles; and 3) inclined treadmill gait training. The first aim of the present study was to examine the effects of the EXECP intervention on motor function, muscle strength, and joint flexibility. We hypothesized that the EXECP intervention would successfully increase performance in the 6MWT (main outcome), GMFM score, muscle strength, and lower limb joint flexibility. The second aim was to examine whether the adaptations induced by the EXECP intervention were still present 3 months after intervention. We hypothesized that all variables would regress toward baseline values after the 3-month retention period, not differing from control values. Finally, we hypothesized that CP participants would have significantly lower values for all studied variables compared with their typically developing (TD) controls.

METHODS

Study Design

Detailed information about the EXECP intervention can be found in our protocol paper (38). A nonconcurrent multiple-baseline design (39,40) was used (Fig. 1). The experimental CP group performed the EXECP intervention and had four testing sessions every 3 months: 1) first pretest (Pre1) at the beginning of the study, 2) second pretest (Pre2) after the 3-month control period, 3) first posttest (Post1) after the 3-month EXECP intervention, and 4) second posttest (Post2) after the 3-month retention period. During the control and retention periods, normal physical activity and physiotherapy were permitted; however, no structured physical training program was allowed. The intervention effects were assessed by comparing both pretests (Pre1, Pre2) with Post1. Because changes during the control period (between Pre1 and Pre2) represent the effects of normal development and activities (e.g., maturation, physiotherapy, sports), only Post1 and Post2 values that were statistically different from both pretests were deemed to have a significant intervention effect. Finally, Post2 was compared with Post1 and the pretests to verify the retention of the adaptations induced by the intervention.

The TD group performed only the two pretests interspaced by 3 months (Pre1, Pre2) and did not take part in the intervention. The Pre2 results were used in TD versus CP group comparisons, because Pre2 had fewer missing data compared with Pre1. Figure 1 depicts the experimental design with all tests.

Participants

A total of 20 children and young adults diagnosed with spastic CP and 17 age- and sex-matched TD controls volunteered for this study. Two participants with CP dropped out during the control period; thus, the final sample was 18 CP and 17 TD participants. The gross motor function classification system (GMFCS; [41]) diagnostic was provided by the participant's neurologist and confirmed by the first author. None of the participants with CP had lower limb surgery, serial casting, pharmacological treatments (except epilepsy medication, $n = 3$; baclofen, $n = 1$) or had participated in a resistance-training program for the lower limbs in the past 6 months. A participant who had a selective dorsal rhizotomy surgery 1 yr ago was included in the sample because his scores for muscle strength, joint flexibility, and gait performance were within the range of the other participants with CP. All participants were able to stand with both heels touching the floor (i.e., ankle in anatomical position). None of the TD participants had any musculoskeletal or neurological impairments. A positive ethical statement was granted by the ethics committee of the Central Finland Healthcare District (U8/2017, amended 7/2021). *A priori* sample size calculation was performed for the main outcome of meters walked in the 6MWT. Using a pre–post parallel-group randomized control trial model as an upper-bound reference, with a power of 0.8 and an α of 0.05, a sample size of 24 participants per group was required. Written informed consent to participate in this study was provided by participants and legal guardians of the underaged (Table 1).

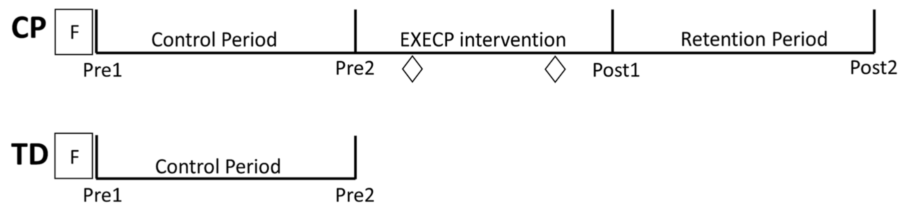

FIGURE 1—Experimental design. Within-group longitudinal analysis in the CP group had four time points for most variables (ankle and knee muscle strength and joint flexibility). The exceptions were as follows: 1) GMFM was measured only at Pre2 and Post1, and (2) trunk muscle strength was measured at the first and last intervention months (diamonds). For the TD group, GMFM and trunk strength were not assessed; thus, all variables were measured at the two time points (Pre1, Pre2). Both groups had a familiarization session (F) before Pre1. Between-group cross-sectional comparisons were done at Pre2.

EXECP Intervention

The EXECP intervention consisted of 2–3 training sessions per week, depending on each participant's physical activity levels: those engaged in regular physical activity chose to perform two or three sessions weekly, whereas sedentary participants were encouraged to train three times per week. A minimum of 24 and a maximum of 36 sessions were enforced for all participants. Each session had the following components and order: treadmill walking (5–10 min), strength training (60–75 min), and flexibility training (0–20 min; only for those with restricted flexibility). All sessions were individually supervised by a physiotherapist or strength and condition coach trained by P. V. Furthermore, gait training at home was performed in addition to the participant's ongoing physiotherapy and other possible sport hobbies.

Strength training. Five single-joint and five multijoint strength exercises were divided into two training protocols performed weekly (i.e., AB or ABA/BAB) with a range of 5–7 exercises per session. The exercises were as follows: seated and standing calf raise, seated DF, knee extension (KE) and flexion (KF) weight machine, leg press, squat, hip flexion while laying down, trunk extension (roman chair), and isometric hollow rocks.

The training load was adjusted monthly. In the first month, three sets of eight repetitions maximum (i.e., the ninth repetition could not be attained), with a movement duration of 6 s (3 s concentric and 3 s eccentric) and 60 s of rest were performed. In the second month, the training volume was maintained while the intensity was increased by reducing the concentric movement duration to 1 s and increasing the rest to 90 s. In the third month, training volume and rest were maintained, but sets were increased to four while repetitions were decreased to six, and concentric muscle actions were done as fast as possible while eccentric movement duration was decreased to 2 s. Exceptionally, the squat exercise followed a different progression: 1 to 4 sets of 10 repetitions with the largest attainable ROM were performed. Movement duration was similar to the other exercises, whereas rest started at 90 s and was decreased, when possible, to 60 s. After the entire volume could be executed with 60 s of rest, balance disks (Casall, Vantaa, Finland) were placed under the participant's feet to cause instability and increase exercise difficulty; also, unilateral squats were used to further increase the exercise intensity. Squats were always performed with the participant holding a support for safety. An assisted training procedure was adopted, the exercise resistance was selected based on the participant's strength on the optimal joint angles, and the instructor assisted in the concentric phase of the movement in the positions where the participant was not able to perform by himself. The eccentric phase was performed unassisted, and constant feedback about movement velocity was given. Whenever necessary, a dense foam ball was used to prevent hip adduction during the lower-limb strength exercises.

TABLE 1. Participant characteristics in the CP and TD groups.

Participant Characteristics	CP (n = 18), Mean ± SD (Min–Max)	TD (n = 17), Mean ± SD (Min–Max)
Male/female	13/5	12/5
Age, yr	14 ± 4 (9–22)	15 ± 4 (9–22)
Height, cm	158 ± 14 (131–180)	161 ± 16 (133–188)
Weight, kg	51 ± 16 (29–81)	53 ± 17 (28–90)
Level of involvement, bilateral/Unilateral	6/12	n/a
GMFCS, I/III	14/4	n/a

n/a, not applicable.

Flexibility training. Four sets of 45-s manual passive-static stretching at the pain threshold (i.e., position where the participant acknowledges an initial stretch pain sensation) were performed for each muscle group diagnosed short in the pretests (38). The possible trained muscles were one- and two-joint hip flexors, hip adductors, and knee flexors. One- and two-joint hip flexors were stretched in the modified Thomas test position (42). The participant laid supine on a table holding one of the lower limbs in full hip flexion (assistance was provided when needed), whereas the other leg hung outside the table (i.e., hip extension). The only difference between the stretches was that the trainer applied the hip extension torque at the distal thigh with the knee joint positioned either in full flexion or in a relaxed position. The hip adductors were stretched with the seated butterfly stretch. The hamstrings were stretched in supine position, and the trainer secured the untrained leg on the bench then flexed the participant's hip to approximately −90° (anatomical position, 0°; negative values, hip flexion) while applying a KE torque at the posterior aspect of the shank.

Gait training. A portable mechanical treadmill with an adjustable inclination of 6° or 7.3° (Vida XL, Venlo, the Netherlands) was used for training. Participants were instructed to walk at a comfortable speed, avoid toe walking, and try their best to attain heel strike. Verbal feedback was constantly given to improve gait quality, and the participant was allowed to rest at any time. In addition to 5–10 min of gait training in every session, all participants received a treadmill to take home and were asked to walk a minimum of 10 min every day also at a comfortable speed, throughout the intervention duration. Weekly walking duration was logged on to a diary by the participants or their guardians, and total gait training duration was calculated. During the retention period, the participants chose if they wanted to keep using the treadmill at home and updating their diary or stop and return it.

Testing Protocol and Data Analysis

Muscle strength: ankle joint. Maximum isometric and concentric ankle plantarflexion (PF) and DF were assessed using a custom-build motor-driven dynamometer (Neuromuscular Research Center, University of Jyväskylä, Jyväskylä, Finland). Participants were seated with the knee joint fully extended (0°), hip joint flexed at −60°, and the ankle joint at an initial position of 0° (i.e., anatomical position) or 28° into PF. The foot was firmly attached to a footplate mounted on the rotation platform so that the rotation axes of the ankle joint and the motor-driven platform coincided. Participants were securely stabilized by an assembly of straps that fastened both shoulders and connected to a waist belt. An additional strap with a foam support prevented the tested leg knee joint from flexing. The torque around the rotational axis of the motor was measured by a piezoelectric crystal transducer (Kistler Holding, Winterthur, Switzerland), and the ankle joint angle was monitored by a linear potentiometer. Torque and joint angle were sampled at 1 kHz with a 16-bit A/D converter (CED power 1401; Cambridge Electronic Design, Cambridge, UK) using Spike2 software (v4, Cambridge Electronic Design).

The PF test started with a 2-s maximum isometric muscle action at 0°, followed by an isokinetic (14 $\text{deg}\cdot\text{s}^{-1}$) concentric effort until 28°. The DF test started with a 2-s maximum isometric muscle action at 28°, followed by an isokinetic (14 $\text{deg}\cdot\text{s}^{-1}$) concentric effort until 0°. Three to five trials with 1–2 min of rest in between were performed for each test, and the highest value among all trials was used for the following variables: peak isometric torque, rate of force development, concentric angular impulse, and curve width. Rate of force development was calculated from the onset of the muscle action (i.e., torque >1 N·m) to 200 ms as delta torque divided by delta time. Concentric angular impulse was calculated as the torque–time integral. Curve width was defined as the concentric ROM where the participant was able to exert continuously at least 50% of the peak isometric torque (43). Figure 2 depicts the four studied variables. No gravity correction was performed on torque data for two reasons. Firstly, the passive delta torque between the two end positions (0° and 28°) was very small (0.5–2 N·m), because of the foot's small moment arm and weight. Secondly, the CP participants had high variability in background muscle activity.

Muscle strength: knee joint. Maximum isometric and concentric KF and KE were assessed using a custom-build motor-driven dynamometer (Neuromuscular Research Center, University of Jyväskylä). Participants were seated with the hip joint flexed at −80° and the knee joint fully extended (0°) or at 105°. The distal part of the shank was secured with a Velcro strap to a strain gauge capable of measuring both tensile and compressive forces. The distance from the dynamometer axis of rotation, aligned with knee joint axis of rotation, to the strain gauge (i.e., moment arm) was measured in each test. Participants were securely stabilized by an assembly of straps fastening both shoulders and connected to a waist belt. The KF test started with a 2-s maximum isometric muscle action at 0°, followed by an isokinetic (15 $\text{deg}\cdot\text{s}^{-1}$) concentric effort until 75°. An examiner kept strong downward pressure at the distal part of the thigh to prevent hip flexion during the trial. The KE test started with a 2-s maximum isometric muscle action at 75°, followed by an isokinetic (15 $\text{deg}\cdot\text{s}^{-1}$) concentric effort until 0°. Torque was calculated by multiplying the moment arm by the force, and joint angle was monitored by a linear potentiometer. Both signals were sampled at 1 kHz with the same hardware and software used in the ankle joint tests. Passive trials (i.e., passive joint movement) were used to measure torque caused by the weight of the leg, which was subtracted from the active torque curves.

The same test procedures (number of trials and rest) and test variables described for the ankle joint tests were used for the knee joint tests. For all strength tests, a preparatory activity consisting of 10 progressively stronger efforts from 20% to 90% of the perceived maximum voluntary effort was performed before each strength test. Both ankle and knee dynamometers performed the target movement velocities with less than 2% variation throughout all trials in this study. All strength measurements were performed on the most affected leg for the CP group and on the corresponding leg of the matching control participant. Participants were instructed to produce maximum isometric torque as fast as possible and maintain maximum effort throughout the concentric movement in each trial. Furthermore, visual feedback of the torque signal was provided in real time, and participants received strong verbal encouragement during every trial.

Muscle strength: trunk muscles. Because both the trunk extension on the roman chair and hollow rocks exercises were trained isometrically and both time and weight recorded in every training session, the best performance in the first training month (to avoid learning effects) and in the last month was used to evaluate strength gains in these muscle groups. Best performance was measured in time, as the duration of the isometric muscle action (maximum 60 s), and intensity, as the maximum weight held during the isometric muscle action. Once the participant was able to hold a given weight for the maximum duration, the intensity was increased.

Joint flexibility. Hip flexor flexibility was tested using the modified Thomas test position described in the flexibility training section. An assistant kept a goniometer with its fulcrum at the greater trochanter of the femur and held the stationary arm perpendicular to the bench. The examiner placed the goniometer's moving arm aligned to the lateral femoral condyle and slowly pushed the distal aspect of the thigh toward hip extension and, once the participant acknowledged an initial stretch pain sensation, read the resulting joint angle in the goniometer. Participants with less than 20° of hip extension were diagnosed with short hip flexors. Hip adductor flexibility and the differentiation between one-joint and two-joint

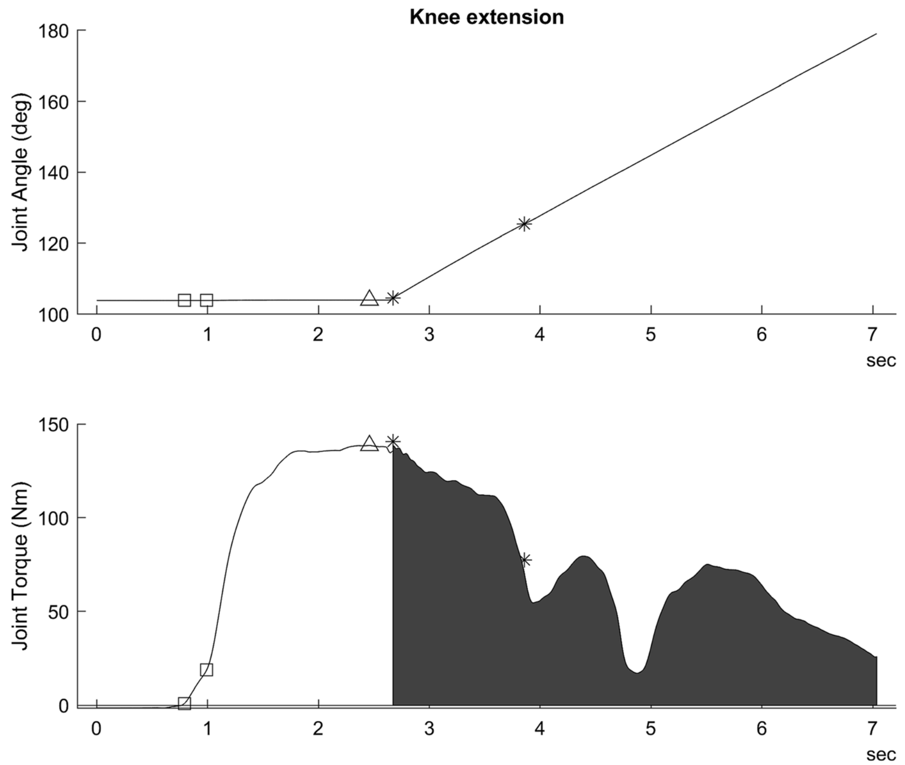

FIGURE 2—Example of the muscle strength variables analyzed in the KE test. From left to right: 1) rate of force development was calculated as the slope between torque onset (>1 N·m) and torque onset plus 200 ms (two squares), 2) peak isometric torque (triangle), 3) concentric angular impulse (shaded dark area), and 4) curve width is the concentric ROM that is greater than 50% of the peak isometric torque (range between the two asterisks). Concentric movement onset is marked by the first asterisk.

hip flexor flexibility were assessed based on the modified Thomas test position (i.e., hip and knee angles); details can be found at the protocol paper (38).

Passive knee extension (PKE) test was performed in the same position as the hamstring stretch, with the participant lying supine with the hip and knee flexed at right angles. The examiner slowly applied torque at the posterior aspect of the shank causing KE, whereas an assistant maintained strong downward pressure on the untested thigh to stabilize the pelvis. The test stopped when the participant acknowledged an initial stretch pain sensation, and the examiner read the goniometer angle (fulcrum: lateral femoral condyle, reference lines: lateral malleolus and greater trochanter of femur). Three measures per leg for each test were performed, and the mean value was used for statistical analysis. Participants with more than 40° of KF in the passive KE test were diagnosed with short knee flexors.

Motor function. Motor function was assessed with two tests, the 6MWT and the GMFM. The 6MWT was performed on an indoor 30-m rubber track, and its result was the distance walked in 6 min. GMFM was assessed in the CP group at Pre2 and Post1 using the absolute scores of the 66-item version of the GMFM (34) dimensions D (standing) and E (walking, running and jumping).

Maturation. Because of the 9-month study duration and a sample composed mainly of children, the growth spurt could be a confounding factor in our experimental design. The estimated time from peak height velocity (i.e., maturity offset, or MO) was computed for all participants at each testing point using sex-specific equations provided by Moore et al. (44), described in our protocol paper (38). For all available data points (i.e., participants multiplied by tests minus data loss: 100 of 106), the participants had an MO smaller than 6 months in only two tests, participants had MOs of 6–12 months in eight tests, and MOs larger than 1 yr in all remaining 90 tests. Thus, for our sample, the growth spurt was not an issue and MO was not included as a covariate in our statistical model.

Test–retest reliability. Before the first test time point (i.e., Pre1), all participants performed a 60-min familiarization session to experience all strength and flexibility tests, and the 6MWT (not necessarily the whole test). Whenever feasible, the familiarization session was used to duplicate tests to allow comparison with Pre1 for test–retest reliability assessment. However, because of limited time in the familiarization session, not many tests could be performed, and only variables with a minimum of five participants were used for this analysis. The two-way mixed-effects absolute agreement intraclass correlation coefficient (ICC; 3.1/3.k; [45]) was calculated between tests (i.e., familiarization vs Pre1) for each group, and flexibility data from both legs were pooled.

Statistical Analysis

Generalized linear mixed models (GLMM) were used to compare the four time points (i.e., Pre1, Pre2, Post1, Post2) in the CP group. Time was set as a fixed factor and the subject intercept as a random factor; thus, participants had different y-intercepts but similar regression slopes. The GLMM model used the unstructured correlation structure and the identity link function, and two distributions were tested: normal and gamma. The best distribution for each dependent variable based on the Akaike information criterion and the residuals Q–Q plot was used. Theoretically, higher motor function should be associated with higher 6MWT and muscle strength performance. Thus, for these variables, the absolute Pre2 GMFM score ($GMFM_{co}$) was used as a covariate, centered and conditioned to the mean ± 1 SD. For the statistical analyses, three participant subgroups based on $GMFM_{co}$ were created: high (>mean + SD), mid (within mean ± SD), and low (<mean − SD) scores. The effects of time, $GMFM_{co}$, and their interaction were tested. For the flexibility tests, in addition to time as a fixed factor, the muscle training status (i.e., trained or not trained during the intervention) was also included, and the interaction between time and training status was verified. The amount of stretching performed during the intervention was not used as a covariate because the participants were allowed to maintain their stretch routines throughout the project duration, and keeping track of it through the 9 months was not feasible.

The GLMM model ICC (ICC_{GLMM}; i.e., subject variance divided by subject plus residual variance) was calculated for each dependent variable to verify the percentage of the total variance that was explained by the participants (i.e., random effect, different β_0 for each participant). The total number of gait training minutes and the total number of strength and stretch exercises were tested as covariates to improve the model, because more training volume could translate into better adaptation of the dependent variables. However, none of these variables were successful in improving the models and therefore were removed. Bonferroni *post hoc* and simple effect tests were used to find the specific differences between tests. Because we hypothesized that most changes would occur between pretests and Post1, although most likely nothing would happen between pretests and between posttests, simple effect tests for the interaction term were performed regardless of the omnibus main effect result. Only pre–post differences in which the posttests were significantly different from both pretests were reported and discussed. The rationale for this decision was that only effects that were statistically different from the control period (i.e., Pre1–Pre2), which has its inherent variability, are statistically meaningful. GLMM results are presented as parameter estimates (β), 95% confidence intervals (95% CI), SE, and the P value. The paired t-test or the nonparametric analog Wilcoxon signed rank was used to compare 1) the two time points (Pre1 and Pre2) in the TD group, 2) the CP GMFM values between Pre2 and Post1, and 3) the trunk strength parameters between the first and last intervention months. Independent t-tests or the nonparametric analog Mann–Whitney U test was used to compare Pre2 between groups. All statistical analyses were performed using jamovi 2.3 software (The jamovi project, https://www.jamovi.org). α was set to 0.05.

RESULTS

Training Compliance and Side Effects

The participants with CP performed 24–36 (mean ± SD, 29 ± 4) training sessions, which contained 360–1984 min (683 ± 352 min) of gait training (i.e., supervised sessions plus home training) and 32–96 min (67 ± 16 min) of stretching in the training sessions. Most participants also stretched the same muscles at the physiotherapy or at home. Only five participants chose to continue gait training in the retention period, reporting 600 min of training, 10 min per day as instructed. In a total of 529 training sessions, there were 12 complaints of acute knee pain (2%) by four participants, which subsided in the same day. Furthermore, two participants reported moderate muscle soreness three times, and one subject reported high muscle soreness once and had to recover for a week before restarting training. Finally, one participant reported knee pain during the first week of inclined treadmill training at home, which subsided after online consulting was done to correct the gait movement pattern.

Data Loss

Two CP 6MWT were excluded from the analysis because of noncompliance with test execution guidelines (1 Pre2/1 Post1). Because of the COVID-19 lockdowns, six participants with CP were unable to perform Post2. Furthermore, three participants started the intervention 3 months after Pre2, and one started 5 months after Pre2. Thus, it is conceivable that this lower physical activity period lowered some study variables below the pretests values.

Test–Retest Reliability

Figure 3 presents ICC values and 95% CI for all repeated measures between the familiarization and Pre1 testing sessions. The CP group had the following sample sizes: PF peak torque and rate of force development (n = 8), other PF and all DF variables (n = 5), and PKE (n = 16). The TD group had the following sample sizes: all PF and DF variables (n = 11), 6MWT and all KE/KF variables (n = 7), and PKE (n = 27). Because of the slower familiarization process in the CP group (e.g., mobility and positioning), the 6MWT and KE/KF tests could not be performed in the familiarization session because of time constraints. Most KE and PF variables, PKE and 6MWT had excellent to moderate reliability, whereas DF and KF had a wider 95% CI ranging from excellent to poor reliability (45). Curve width reliability for all four muscle actions was very poor.

Within-Group Comparisons in the Control Period (Pre1 vs Pre2)

In the CP group, no statistically significant *post hoc* test differences for time were found between Pre1 and Pre2 in any of the studied variables. However, a few significant simple effects were statistically significant in the control period: 1) KE peak isometric torque was higher in Pre2 compared with Pre1 in the low $GMFM_{co}$ subgroup (β = 11; SE = 3; 95% CI, 4–17; P < 0.001) and the mid $GMFM_{co}$ subgroup (β = 5;

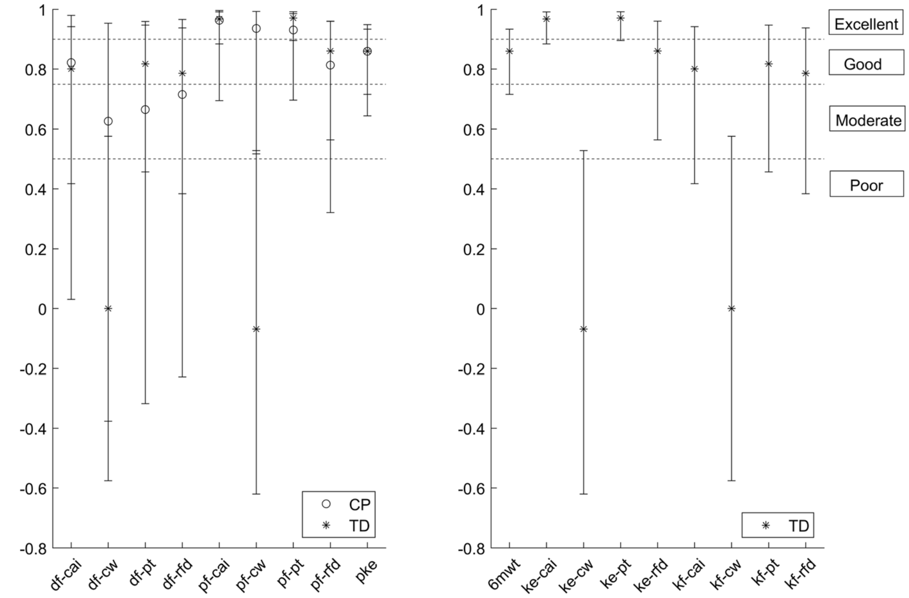

FIGURE 3—ICC and 95% CI for successfully replicated study variables in both groups (*left panel*) and only in TD (*right panel*). The *top right* corner displays reliability thresholds (45). 6mwt, 6-min walking test; cai, concentric angular impulse; cw, curve width; df, dorsiflexion; ke, knee extension; kf, knee flexion; pf, plantarflexion; pke, passive knee extension; pt, peak torque; rfd, rate of force development.

SE = 2; 95% CI, 0–10; P = 0.033), 2) KE rate of force development was higher in Pre2 compared with Pre1 for the high $GMFM_{co}$ subgroup (β = 52; SE = 18; 95% CI, 15–88; P = 0.005), and 3) KF rate of force development was higher in Pre1 compared with Pre2 for the mid $GMFM_{co}$ subgroup (β = 16; SE = 7; 95% CI, 2–30; P = 0.027). Thus, although no differences between pretests were found for the entire CP group, a few subgroups changed significantly during the control period. In the TD group, no statistically significant differences were found between Pre1 and Pre2 in any of the studied variables, with one exception. PF rate of force development was significantly higher in Pre2 compared with Pre1 (mean difference, 65 (N·m) · s^{-1}; $t = -2.686$, P = 0.017).

Within-Group Comparisons for Intervention Effects (Pre vs Post)

Six-minute walking test. Significant main effects of time (i.e., time points) and $GMFM_{co}$ (i.e., GMFM as a covariate) were found ($P < 0.001$), but no time–$GMFM_{co}$ interaction (P = 0.126). *Post hoc* analysis showed that Post1 had statistically higher scores than pretests (β = 33; 95% CI, 12–53; SE = 11; P = 0.024). Likewise, Post2 had statistically higher scores than pretests (β = 43; 95% CI, 20–67; SE = 12; P = 0.006). The simple effects test showed that the three $GMFM_{co}$ subgroups were statistically different in all four time points ($P < 0.001$) and that the pre–post differences occurred only in the two lower score $GMFM_{co}$ subgroups ($P < 0.001$).

GMFM (Pre2 vs Post1). Four participants with CP had the maximum GMFM score at Pre2 (i.e., highly functional) and were excluded from this analysis because of the test insensitivity to measure changes induced by the intervention. The Wilcoxon signed rank test showed a statistically significant difference (n = 14, P = 0.004) between Pre2 (median, 101; interquartile range (IQR), 46) and Post1 (median, 104; IQR, 41) GMFM scores. Eleven participants improved a median of 3 points with a range of 1–11, and three participants had the same score on both tests.

Trunk isometric strength (first vs last intervention month). A statistically significant difference in trunk extension weight between the first (median, 0.5; IQR, 5; P = 0.001) and last (median, 5; IQR, 7) months was found. There was no difference between the duration of the trunk extension exercise in the first (median, 60; IQR, 7) and the last (median, 60; IQR, 0) months. For trunk flexion, the opposite happened: no difference in trunk flexion strength between the first (median, 0; IQR, 0) and last (median, 0; IQR, 0) months was found, whereas the duration of the trunk flexion exercise was statistically lower in the first (median, 45; IQR, 30; P = 0.013) compared with the last (median, 60; IQR, 15) month.

Peak isometric torque. For the PF test, a significant main effect of $GMFM_{co}$ ($P < 0.001$) was found, whereas there were no main effects of time or their interaction. $GMFM_{co}$ subgroups were statistically different in all four time points ($P \leq 0.001$). No significant main effects were found for the DF test. In the KE test, a significant main effect of time ($P < 0.001$) and its interaction with $GMFM_{co}$ (P = 0.014) were found. *Post hoc* analysis showed that Post1 torque was higher than pretests (β = 23; SE = 3; 95% CI, 17–29; $P < 0.001$). The simple effects test showed that the *post hoc* differences occurred for all $GMFM_{co}$ subgroups ($P < 0.001$). In the KF test, only a significant main effect for time was found ($P < 0.001$). *Post hoc* analysis showed that Post1 torque was higher than the pretests (β = 16; SE = 3; 95% CI, 9–22; $P < 0.001$).

Rate of force development. For the PF test, a significant main effect of $GMFM_{co}$ (P = 0.011) was found, with statistically significant differences between the three $GMFM_{co}$ subgroups in all time points ($P < 0.05$), except Post2. For the DF test, a significant main effect of time ($P = 0.034$) was found. However, *post hoc* analysis showed that Post1 was only statistically different from the lower value pretest and thus was disregarded. For the KE test, significant effects of time ($P < 0.001$) and its interaction with $GMFM_{co}$ ($P = 0.005$) were found. *Post hoc* analysis showed that Post1 had higher values than the pretests ($\beta = 68$; SE = 17; 95% CI, 37–101; $P < 0.001$). The simple effects test showed that pre–post effects of time were significant for all three $GMFM_{co}$ subgroups ($P < 0.001$). For the KF test, significant effects of time ($P = 0.12$) and $GMFM_{co}$ ($P = 0.010$) were found; however, *post hoc* analysis and simple effects test revealed no significant pre–post differences.

Concentric angular impulse. For the PF test, a significant main effect for $GMFM_{co}$ ($P = 0.001$) was found. Simple effects test showed that $GMFM_{co}$ subgroups were statistically different in all four time points ($P \leq 0.011$). No significant main effects were found for DF concentric angular impulse. In the KE test, significant effects of time ($P < 0.001$) and its interaction with $GMFM_{co}$ ($P = 0.009$) were found. *Post hoc* analysis showed that Post1 concentric angular impulse was statistically higher than the pretests ($\beta = 46$; 95% CI, 22–70; SE = 12; $P = 0.001$). The simple effects test showed that pre–post differences occurred only in the two lower score $GMFM_{co}$ subgroups (<0.001), and that $GMFM_{co}$ subgroups were statistically different only in the pretests ($P < 0.05$). For the KF test, significant effects for time ($P = 0.005$) and $GMFM_{co}$ ($P = 0.033$) were found. *Post hoc* analysis showed that Post1 concentric angular impulse was statistically higher than the pretests ($\beta = 45$, 95% CI, 19–71; SE = 13; $P = 0.01$). Simple effects test showed that the pre–post differences were only present in the two higher score $GMFM_{co}$ subgroups ($P \leq 0.005$), and that $GMFM_{co}$ subgroups were statistically different in Pre1 and Post1 ($P < 0.05$).

Curve width. No significant effects in PF, DF, and KF curve width were found. In the KE test, a significant effect of $GMFM_{co}$ ($P < 0.001$) was found, while no effects of time or their interaction. Simple effects analysis showed that only in Pre1, the $GMFM_{co}$ subgroups had statistically different curve width values ($P < 0.001$), with higher $GMFM_{co}$ scores having higher curve width.

PKE flexibility. For the PKE test, significant main effects of time ($P = 0.001$) and training status ($P < 0.001$) were found. *Post hoc* analysis showed that the legs chosen for flexibility training during the intervention had statistically lower flexibility compared with the untrained legs ($\beta = 14$; SE = 4; $P < 0.001$), and the simple effects test further revealed that the differences were present in all four time points ($P \leq 0.004$). The second *post hoc* analysis (i.e., merged training status) showed that both posttests had statistically higher joint flexibility compared with the pretests ($P < 0.05$). Furthermore, the simple effects test revealed that pre–post differences were present only in the trained legs ($P = 0.003$). Post1 had significantly higher joint flexibility than both pretests ($\beta = 5$; SE = 2; 95% CI, 1–8; $P = 0.008$), and so did Post2 ($\beta = 4$; SE = 2; 95% CI, 0–8; $P = 0.037$).

Hip extension flexibility. No main effects of time, training status, and their interaction were found for the hip extension test. In addition, *post hoc* tests showed no differences. Oppositely, the simple effects test found a significant effect for time only in the trained legs ($P = 0.019$), and pairwise comparisons showed that Post1 flexibility was statistically higher than the pretests ($\beta = 5$; SE = 2; 95% CI, 1–9; $P = 0.018$).

Within-Group Comparisons for the Retention Period (Post1 vs Post2)

No significant differences between posttests were found in the present study. In all dependent variables with a significant difference between pretests and Post1, Post2 values were in between pretests and Post1 and thus not different from any time points. The only exceptions were the 6MWT and PKE, in which Post2 remained statistically higher than the pretests. Table 2 shows the estimated marginal means for all variables at the best pretest, Post1, and Post2 time points.

Between-Group Comparisons

Table 3 shows the Pre2 comparisons between CP and TD groups and the absolute difference in means between pretests for both groups. The TD group had statistically higher scores for all studied variables compared with CP, except for hip flexion flexibility.

DISCUSSION

The main finding of the present study was that the EXECP intervention successfully enhanced gait performance and overall gross motor function. Furthermore, knee and trunk muscle strength, and hip and knee joint flexibility improved. However, at the ankle joint, no significant effects of the intervention were found. The multicomponent intervention design has the disadvantage of not allowing the determination of the importance of each specific adaptation to the gains in motor function. However, it is reasonable to assume that the combination of the induced adaptations was beneficial. Importantly, the multicomponent training program was safe, feasible, and effective in increasing motor function in children and young adults with CP.

Motor function. We found a group mean increase in 6MWT distance of 33 and 44 m comparing pretests with Post1 and Post2, respectively. Maher et al. (36) performed the 6MWT with a similar sample (CP, same mean age and GMFCS levels; $n = 41$) and found a mean test–retest group difference of 1 m and a 95% CI for individual test–retest variability of ±43 m. Thus, our intervention effect seems clinically significant as it is very unlikely that the group mean would shift toward the upper test–retest variability bound per chance. Interestingly, Gillet et al. (14) induced similar changes in the 6MWT (mean difference, 48 m) with a combined strength training for ankle muscles and anaerobic training program for slightly older participants with CP (mean age, 20 yr). Oppositely, Kirk et al. (15) performed a strength training

TABLE 2. EMM, SE, and ICC_{GLMM} for all study variables at the best pretest and both posttests for CP participants.

Variable	ICC_{GLMM}	Pretest, EMM (SE)	Post1, EMM (SE)	Post2, EMM (SE)
6MWT, m	0.87	502 (21)	535 (21)*	546 (21)*
PKE trained, °	0.73	39 (5)	35 (5)*	35 (5)*
PKE untrained, °		24 (4)	21 (4)	22 (4)
Hip trained, °	1.00	19 (3)	24 (3)*	18 (4)
Hip untrained, °		26 (3)	24 (3)	24 (4)
PF torque, N·m	0.74	74 (6)	81 (6)	81 (7)
PF RFD, $(N{\cdot}m){\cdot}s^{-1}$	0.49	93 (15)	119 (15)	95 (17)
PF CAI, (N·m)·s	0.83	68 (10)	77 (9)	81 (10)
PF CW, °	0.99	17 (2)	16 (2)	17 (2)
DF torque, N·m	1.00	25 (4)	25 (4)	26 (4)
DF RFD, $(N{\cdot}m){\cdot}s^{-1}$	1.00	56 (9)	60 (10)	61 (10)
DF CAI, (N·m)·s	0.84	15 (4)	18 (4)	19 (4)
DF CW, °	0.66	14 (2)	13 (2)	14 (2)
KE torque, N·m	1.00	95 (11)	113 (11)*	103 (11)
KE RFD, $(N{\cdot}m){\cdot}s^{-1}$	1.00	218 (36)	286 (37)*	264 (39)
KE CAI, (N·m)·s	0.79	190 (21)	236 (21)*	233 (23)
KE CW, °	0.23	40 (4)	41 (3)	39 (4)
KF torque, N·m	1.00	52 (6)	68 (7)*	62 (7)
KF RFD, $(N{\cdot}m){\cdot}s^{-1}$	1.00	86 (13)	79 (12)	102 (15)
KF CAI, (N·m)·s	0.64	49 (16)	94 (16)*	73 (18)
KF CW, °	0.55	18 (5)	20 (5)	18 (5)

*Different from pretests ($P < 0.05$).
CAI, concentric angular impulse; CW, curve width; EMM, estimated marginal means; RFD, rate of force development.

program for lower limbs and trunk muscles for adults with CP (mean age, 36 yr), and although their gait kinematics and muscle strength improved, no change in the 6MWT was found. In all the three studies mentioned previously, participants had similar GMFCS distributions and a baseline 6MWT performance of 480–502 m, the interventions had adequate strength training load distribution, and other than the age differences, the only major difference was in the chosen training protocol structure. Although Gillet et al. (14) utilized anaerobic exercises very relevant to motor function (e.g., stair climbing, changing direction), and we trained gait on the treadmill, the protocol from Kirk et al. (15) may have failed to increase 6MWT because of the lack of a more generalized motor function training to enhance coordination. Regarding the GMFM scores, merging GMFCS I–III and GMFM dimensions D and E, Oeffinger et al. (46) reported a minimum clinically important difference of 1.2–1.6 and 1.8–2.6 for medium (0.5) and large (0.8) effect sizes, respectively. In the present study, absolute GMFM score changes ($n = 11$; median, 3) were equal or higher than two points for 9 participants and one point for two participants. It is worth considering that a one-point increase may or may not be functionally relevant. For example, five participants were able to climb stairs with alternating feet after the intervention, instead of stepping twice on the same step, as they did before the intervention. Other one-point increases, for example, being able to keep balance with one foot up from 2 to 4 s may not be so functionally relevant.

TABLE 3. Group comparisons for all studied variables at Pre2 session.

Group	Mean ± SD/Median (IQR)			Δ Pretests
Variables	CP	TD	P	CP/TD
6MWT, m	550 (135)	710 (106)	<0.001	1/4
PKE, °	34 (28)	13 (20)	<0.001	
Hip, °	21 ± 8	24 ± 6	0.124	
PF torque, N·m	75 (53)	163 (75)	<0.001	3/4
PF RFD, $(N{\cdot}m){\cdot}s^{-1}$	67 (68)	397 (274)	<0.001	15/43
PF CAI, (N·m)·s	58 (56)	208 (106)	<0.001	11/9
PF CW, °	13 (15)	25 (4)	0.004	1/0.5
DF torque, N·m	21 (15)	38 (26)	<0.001	2/3
DF RFD, $(N{\cdot}m){\cdot}s^{-1}$	43 (22)	136 (48)	<0.001	9/4
DF CAI, (N·m)·s	14 (19)	58 (23)	<0.001	2/7
DF CW, °	12 (17)	28 (0)	<0.001	0/1
KE torque, N·m	92 (53)	125 (104)	0.018	2/3
KE RFD, $(N{\cdot}m){\cdot}s^{-1}$	109 (237)	388 (291)	0.001	33/13
KE CAI, (N·m)·s	202 (145)	346 (356)	<0.001	0/24
KE CW, °	37 ± 19	52 ± 14	0.013	7/7
KF torque, N·m	46 (46)	63 (57)	0.030	5/6
KF RFD, $(N{\cdot}m){\cdot}s^{-1}$	29 (64)	155 (232)	<0.001	6/41
KF CAI, (N·m)·s	40 (74)	147 (172)	<0.001	14/4
KF CW, °	9 (21)	39 (20)	<0.001	4/3

"Δ Pretests" indicates the absolute difference between pretests means for both groups (e.g., for the 6MWT the mean difference was 1 and 4 m for the CP and TD groups, respectively).
CAI, concentric angular impulse; CW, curve width; RFD, rate of force development.

Muscle strength. Thigh muscles responded well to the EXECP intervention. KE had an increase of 19% in peak torque, 31% in rate of force development, and 24% in concentric angular impulse, whereas KF had an increase of 31% in peak torque and 92% in concentric angular impulse. Acknowledging that previous studies had different training loads, testing procedures, and CP populations, we think that all studies discussed hereinafter had adequate training loads and testing procedures and thus will be cautiously compared with the present study. Previous studies reported similar gains for KE peak torque (12%–27%; [18,19]), concentric KE/KF peak torque (25%), and work (21%; [16]). Kirk et al. (15) reported a one-repetition maximum (1RM) increase of 82% for KF and 45% for KE, which is fairly comparable to our concentric angular impulse variable (i.e., assuming a similar repetition duration) and has similar magnitude strength gains. The increase in KF concentric angular impulse was exceptionally high, and it is probably not a result of only increased muscle strength but also enhanced motor control to maintain higher torque output throughout the concentric muscle action, even though curve width did not increase significantly after the intervention.

Our intervention did not cause significant changes in the strength of the shank muscles, which is in contrast with other studies that successfully induced adaptations in PF peak torque (25%; [14]), and in PF and DF 1RM (137% and 87%, respectively, [15]). Gillet et al. (14) had a similar training load to that used in our study; however, most of their exercises (four of five) trained PF, whereas one trained DF. Thus, it is reasonable that they successfully increased PF peak torque, whereas no changes were reported for the DF. Kirk et al. (15) also had a similar training load compared with the present study and reported a large increase in PF (137%) and DF (87%) 1RM test, in the same device that training occurred. However, no changes in DF peak torque and rate of force development were found when measured by a stationary dynamometer (increases in rate of force development in shorter time windows were found), suggesting that specificity between testing and training is an important factor. In the present study, the PF testing position had the knee and ankle at the anatomical position, which placed both hamstrings and gastrocnemius muscles in a lengthened and often slightly uncomfortable position (participants with CP consistently asked to flex their knee during rest). Because the weight used for exercising these muscles consistently increased for all participants during the intervention, we hypothesize that the testing position may have blurred the strength gains for PF. Lastly, DF was the only muscle action trained with manual resistance and rubber bands, highly dependent on the ability of the trainer to keep the appropriate stimulus. Therefore, these aspects may reduce the efficiency of training these ankle muscles, and a higher training load may be required for adaptations to be verified.

The EXECP intervention was not able to increase curve width in any of the four muscle actions, not even in the thigh muscles, which had a significant increase in concentric angular impulse, demonstrating an inability to maintain steady torque output during the movement. This result is reasonable, because only the first training month of the intervention had an optimum training load configuration (i.e., slow and controlled movement) for curve width enhancement. Increases in trunk muscles strength followed an expected pattern: a) for trunk extensors, maintaining the maximum exercise duration (60 s) was already possible in the first month of the intervention for 12 participants, and thus, increasing the weight (900%) was the main procedure for increasing the training load; and b) for trunk flexors, only five participants were able to achieve the maximum exercise duration (60 s) in the first month, and thus, increasing the hold duration (33%) was the main way to increase the training load. In addition, a slight increase of weight in the trunk flexion exercise (i.e., weight on the distal shank and held above the head) causes a large increase in difficulty due to the very long resistance arm. Finally, because the participants were not used to progressive resistance training, increases of muscle strength may be affected by psychological aspects (e.g., willingness to exert maximum efforts), as the 10-fold increase in trunk extension weight suggests.

Joint flexibility. The EXECP intervention caused a mean joint flexibility increase of 5° for both passive knee and hip extensions. Although statistically significant, the change magnitude seems functionally insignificant, although it was achieved with a low training volume (mean of 6 $\text{min}\cdot\text{wk}^{-1}$), and it is unclear if a higher training volume could have yielded a better outcome. Furthermore, it is also unclear if the enhanced flexibility was due to sensorimotor (i.e., increased tolerance to stretch) or structural adaptations (i.e., morphological changes in the muscle–tendon structure), as this topic is still under active investigation (28,47). It seems unlikely that flexibility training with a feasible training load can induce mechanical alterations in most participants with CP. We base this claim on the following arguments: 1) for clinical populations, there is an overall lack of evidence for stretching effectiveness (48) and specifically for CP (23,24); 2) morphological alterations in CP muscle, such as a lower number of satellite cells and ribosomes, should mechanistically hinder muscle growth response (1,49,50); and 3) sarcomerogenesis is hindered in CP, evidenced by the usual reduced number of lengthened sarcomeres found in CP muscle (1). Given the widespread use of stretch as a treatment for CP and the lack of evidence of its effectiveness, current therapeutic practices should focus on other interventions that have been shown successful, such as strength and gait training. Finally, our data show that the intervention had no negative effect on joint flexibility, which has been an anecdotal concern of many health practitioners.

Covariates. Overall, GMFM_{co} was very useful in improving the GLMM models. GMFM_{co} was expected to affect the 6MWT outcome because it includes many items related to gait, but GMFM_{co} also worked very well for PF and KE (torque, rate of force development, and concentric angular impulse) and KF (rate of force development and concentric angular impulse). Interestingly, GMFM_{co} was not useful to stratify participants in any of the DF variables, meaning that participants with high GMFM scores had similar performance than participants with low scores. Training load variables such as total number of training sessions and strength exercises, amount of gait training, and number of stretching exercises had no effect on the models. Participants with higher GMFM were able to perform more exercises during the training session because of improved training logistics (e.g., faster locomotion, easier setup attainment) and generally were more physically active. Furthermore, group heterogeneity was a much more prominent factor compared with the training load, which is evidenced by the high ICC_{GLMM} displayed in Table 2.

Control and retention periods. Maturation and normal daily activities did not affect the studied variables in both groups during the control period, except for PF rate of force development in the TD group. A few CP GMFM_{co} subgroups had significant changes between pretests for KE (peak torque and rate of force development) and KF (rate of force development), although nonsignificant for the whole group. Although not significant, a clear declining trend toward pretest values was found in Post2, which was expected because the intervention stopped at Post1. This result suggests that a lifelong change in behavior is needed for people with CP: physical training must be continued throughout the person's life span.

Group comparisons. TD had superior performance in all dependent variables, except for hip extension flexibility. It is reasonable to infer that all these aspects of muscle strength and motor control should be targeted during an intervention. Regarding hip extension flexibility, only two participants had low flexibility (<20), and both group medians were very similar; thus, in our sample, hip extension flexibility was not a main problem for CP participants.

Study limitations. The main study limitation was the sample size; it was unfeasible to reach 24 participants because of constraints of time and resources. The ICC_{GLMM} displayed in Table 2 shows that the within-group variability was very large and that allowing the model to have a β_0 (i.e., y-intercept) for each participant was very helpful. A higher sample size would allow the use of the participants as a random effect, making it possible to find clusters of participants with different slopes (e.g., responders and nonresponders). Test–retest reliability (i.e., ICC) was adequate for PKE, 6MWT, and most KE and PF strength variables, whereas the lower 95% CI bounds of DF and KF strength variable reached the poor reliability threshold. This result suggests that similar intervention studies should perform longer familiarization sessions and at least two pretests before an intervention, not only to verify maturation effects but also to evaluate the test–retest variability. Because Maher et al. (36) had reliability data for the 6MWT with a similar sample, we chose to use the available time to duplicate other measures. Overall, curve width for both groups had very poor reliability even with a familiarization session, clear instructions, and multiple trials per test, suggesting that this measurement is not reliable and should be modified in future studies. Another important inherent limitation of training studies is that not all training sessions were optimal: participants were sometimes tired, in a bad mood, or unmotivated. Thus, optimizing training for good execution and attitude, nutrition, and resting is a process that surely demands more than 3 months. Lastly, the criterion for diagnosing hip flexors shortness was 20° of hip extension, as it is evident that hip extension is necessary during the late stance phase of gait. Please note that, in our protocol paper, 0° was incorrectly mentioned as the criterion.

CONCLUSIONS

The EXECP intervention was effective in enhancing gait performance and overall gross motor function. Furthermore, the training program containing strength, flexibility, and gait training was found safe and feasible for children and young adults with CP. Hopefully, this intervention will inspire physiotherapists, trainers, and individuals with CP to pursue long-term training for a better, more functional life.

Analysis scripts can be found at https://github.com/Pedro-Valadao/EXECP. Raw data will be made available as soon as EXECP's subproject ISENS finishes its data analysis and all data can be properly anonymized.

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All authors have read and approved the final manuscript. The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest. The results are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation. The results of the present study do not constitute endorsement by the American College of Sports Medicine.

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