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Original Article

Effects of a 4-week neuromuscular training on contralateral pelvic drop in female runners

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Abstract:
The purpose of this study was to investigate the effects of 4-week neuromuscular training programs on contralateral pelvic drop (CPD) in recreational female runners. Thirty-two female runners who experienced CPD volunteered for the study. The participants were divided into 4 groups with eight participants in each group. The first group received part correction training (PCT), where the participants received audio and visual feedback during step single leg squat (SSLS) exercises; while the second group performed whole correction training (WCT), where the participants received audio and visual feedback during running. The third group performed part correction training followed by whole correction training (PWCT), where the participants began the training with SSLS for 2 weeks followed by running for the last two weeks. The last group performed whole correction training followed by part correction training (WPCT), where they began their training by running before doing SSLS. The participants were assessed for contralateral pelvic drop angle (CPDA) during midstance using 3D motion analysis. A mixed model ANOVA was performed to investigate the effects of the four neuromuscular training approaches. The level of significance was set at 0.05. The obtained results showed that the group × time interaction was statistically significant in CPDA, $F_{(6,56)} = 18.177$, $p < 0.000$, $\eta^2 = 0.661$. *Further analysis suggested that WPCT was the most effective program in addressing CPDA during 4-week neuromuscular training.* The findings showed that the participants utilized WCT to internalize the concept of whole movements and capitalized on part correction by increasing the interaction of synchronization for simplifying and coordinating muscle activities to mechanically control unstable joints.
Key Words: **pelvic drop, neuromuscular training, running economy, recreational runners, whole-part sequence**

Introduction

Contralateral pelvic drop (CPD) refers to a condition when the opposite hip of the weight-bearing leg is lower than its counterpart in the frontal plane (Souza & Powers, 2009); CPD is one of the leading indicators to identify runners with injuries. Bramah, Preece, Gill, and Herrington (2018) showed that an increase in pelvic drop by 1° increased the chances of injuries by 80%. Furthermore, CPD is more commonly found in female runners than in male runners. Female runners have a 5.3 times higher risk of suffering from running-related injury (RRI) owing to CPD than male runners (Ireland et al., 2012).

CPD can be caused by many factors. Studies have shown that weakness in hip abductor may contribute to CPD (Willson et al., 2012). While many researchers believe that weaknesses in hip abductor cause CPD, several researches found no improvement in CPD after implementing a hip abductor strengthening program (Fields, 2011; Heiderscheit, 2010; Hollman et al., 2009; Sami, Muaidi, & Ahsan, 2021). Willy and Davis (2011) discovered that the hip angle was improved possibly owing to neuromuscular training, which helped to improve movement adaptation in runners. Neuromuscular training (NT) capitalizes on verbal feedback and, sometimes, visual feedback to let participants acknowledge their movement inefficiency and improve or correct the inefficient movements by focusing their attention on verbal instructions. NT training can be used to target the hip abductor muscles' ability to stabilize the pelvis by resisting external moments during functional tasks (O'Driscoll & Delahunt, 2011).

The effectiveness of NT depends on the complexity of movement tasks, the ability to interpret and process verbal and/or visual instructions, and on how the instructions are given. Movement complexity is defined as how dependent sequences or parts are to a specific skill. Tasks are more complex if they involve more dependent sequences or parts. Correction techniques are divided into two principles, i.e., part correction or whole correction. Part correction technique addresses only one single dependent sequence of movement. Hence, the given instruction is concise, specific and easily interpreted and addressed. In contrast, whole correction technique concentrates on entire movement. Thus, given instruction is relatively less concise and more difficult to interpret and address. However, participants gain a better understanding and appreciation of the kinesthetic principle of the entire movement process (Fontana et al., 2009; Park et al., 2004). Whole correction technique

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has been shown to be an effective correction strategy for movements with high interlimb coordination such as, running (Fontana, Furtado Jr, Mazzardo, & Gallagher, 2009; Swinnen & Carson, 2002; Wenderoth, Puttemans, Vangheluwe, & Swinnen, 2003). To our knowledge, there are no studies that compared the effectiveness between these two correction techniques. Therefore, the purpose of this study was to compare the effects of four neuromuscular training programs (i.e., part correction training, whole correction training, combined part-whole correction training and combined whole-part correction training) during four weeks of exercise. The obtained results provide insights and indicate which training methods should be used to minimize training period while maximizing running performance.

Materials and methods

Participants

Thirty-two long-distance recreational female runners (age: 36.03 ± 6.26, height: 159.44 ± 4.63 cm; weight: 51.52 ± 5.03 kg; %body fat: 26.13 ± 3.22; Vo_2max: 40.84 ± 6.83 ml/kg/min) volunteered to participate in this study. The participants were required to pass the following inclusion criteria: 1) female runners aged between 24 and 45 years old with a heel strike running pattern; 2) leg length difference was not over 1.5 cm; 3) participants exhibited positive of dynamic pelvic drop test. To assess the dynamic pelvic drop test, flat markers were placed on both sides of Posterior Superior Iliac Spine (PSIS). The participants were asked to run for 30 min on a treadmill (Sprintex Natural movement, USA) at their natural pace. The researcher recorded the contralateral pelvic drop angle (CPDA) during the last five running cycles every 10 min and evaluated the average CPDA during midstance phase by the Kinovea software 0.9.4 version (Kinovea, Korea). If the average pelvic drop was over 5° from the PSIS line during running on the non-weight bearing side, the participants were assessed as positive (Huntley, 2003). The participants were excluded if they requested to withdraw or participated in the training session for less than 80% of the time.

Ethics approval was granted by the Human Research Ethics Review Committee of the University and complied with the principles of the Declaration of Helsinki. All participants were informed of the risks and benefits of the study and written informed consent was received from all participants prior to their participation in the study.

Procedure

The testing session (pretest, mid-test, and posttest) took 2 days to ensure maximum performance and minimum fatigue. The participants performed an isokinetic strength test on the first day to measure hip muscle strength. CPDA test was performed on the second day. The participants performed a VO_2max test after isokinetic strength test at pretest to determine the velocity at VO_2max for training.

The VO_2max test was conducted on a treadmill (HP Cosmos Pluto version, Germany) at an incline of 1° to account for the effect of air and wind resistance that occurs during typical outdoor running conditions (Jones & Doust, 1996). The participants were outfitted with a breath-by-breath metabolic system (Cortex Biophysik, Leipzig, Germany). Each participant began a 3-min warm-up at a speed of 6 km/h. Speed was increased by 1 km/h every 1 min until volitional fatigue. Once exhaustion was reached, the participants performed a 4-min cool down where the speed was reduced to 5 km/h. The velocity at VO_2max was the minimal speed the participants were able to sustain for at least 1 min since they reached VO_2max. If they were able to maintain their speed for 1 min, the velocity during the previous stage was recorded as velocity at VO_2max (vVO_2max).

Measurements

Isokinetic strength test

The muscle strength of the gluteus medius was measured using isokinetic dynamometry. Because the main purpose of this study was to compare neuromuscular adaptations after training, the isokinetic test helped to reduce confounding factors owing to an increase in strength. To evaluate hip strength of concentric and eccentric contraction, the participants performed five continuous maximal HBD-HDD tests at 60°/s. The test started with the dominant leg and followed by the non-dominant leg (Lourencin et al., 2012). The isokinetic peak torque was normalized to body weight (Nm/kg).

Contralateral pelvic drop angle test

CPDA was evaluated using a 3D motion analysis system (Qualisys Track Manager, QTM 2.15 build 3300, Sweden). Thirty-five retroreflective markers were placed bilaterally following the Qualisys PAF. After the markers were attached to the participants, the participants performed a 5-min running as a warm-up. Then, they were instructed to run on a treadmill for 18 min where the participants ran for 6 min at 65% of velocity at VO_2max before running for 6 min at 75% and for another 6 min at 85%.

Data during the stance phase of the last 6 min were collected to compute the CPD angle because 85% of velocity at VO_2max was the sub-maximal speed that the participants were able to maintain. The stance phase occurred when the marker on the lateral malleolus of the swinging leg was in parallel with the marker on the lateral malleolus of the stance leg. On average, there were 12 running cycles in1 min. As a result, 72 CPD data points were collected by Visual 3D (C-Motion, Inc, Rockville, MD) and MATLAB software (Mathworks, Inc., Natick, MA). To calculate CPDA, a vector calculation similar to the angle between two plane was employed, where CPD is the angle between a pelvic plane and a transverse plane. The pelvic plane was located between the sacrum, left ASIS, and right ASIS. CPD angles were measured in degrees, and the average value of CPD was used for further statistical analysis.

Neuromuscular training program

Each group trained for 4 days a week for 4 weeks (a total of 16 sessions). Because our focus was only on neuromuscular training, the training period was 4 weeks to eliminate potential influence of hypertrophic muscle changes on running mechanics (Moritani, 1979). During the 1st session, the participants were asked to run on a treadmill (Sprintex Natural Movement treadmill, USA) for 3 min using their habitual running form at their natural speed. After finishing 3-min habitual running, the researcher explained the movement pattern and running mechanics to the participants only during the first session. The training sessions in each group had a similar pattern. They received both visual and verbal real-time feedback during training. In each session, markers were taped to the right and left sides of PSIS The hip line indicated the hip level of the participant. The hip line was provided in real-time on a monitor placed in front of the participants.

***Part correction training (PCT)*:** Step single leg squat (SSLS) was performed in PCT. SSLS was selected owing to its similarity to midstance phase during running. Upon arrival, the participants were attached with a marker tape on the right and left side of PSIS. SSLS was performed in front of a monitor. The monitor was connected to a motion analysis program (Kinovea software 0.9.4 version, Korea). The training program is presented in Table 1. The participants started training with their dominant leg followed by non-dominant leg to finish a set. While performing SSLS, they were able to see the hip level line on a monitor. Moreover, the participants were able to see a red line indicating if CPD was exhibited. CPD was exhibited if the angle between the hip line and the horizontal line exceeded 5 degrees. The participants received instructions by the researcher to “step forward with soft landing”, “bend the knee with the knee pointing forward while keeping both hips level”, and “come up with the knee still pointing forward with both hips remaining level”. The verbal cue was faded as shown in Table 1.

Table 1. Part correction technique (PCT) 4-week training program (4 days/week)

Week	Step single leg squat (reps/side)	Rest (min)	Set
1	12	2	3
2	12	2	3
3	15	2	5
4	15	2	5

***Whole correction training (WCT)*:** The participants in WCT performed running exercise as indicated in Table 2 The setup of WCT was similar to that of PCT, where the participants were able to see if they experienced CPD on a monitor. The following verbal cues were provided to the participants: “run softer”, “knee pointing straight to the front and keep the knee window wide apart from your hip”, and “keep both sides of the hip at the same level”.

Table 2. Whole correction technique (WCT) for 4-week training program (4 days/week)

Week	%Velocity of vVo_2max	Rest/ set (min)	Set
1	65% (5 min), 75% (5 min), 85% (5 min)	3	3
2	65% (5 min), 75% (5 min), 85% (5 min)	3	3
3	65% (10 min), 75% (10 min), 85% (10 min)	5	3
4	65% (10 min), 75% (10 min), 85% (10 min)	5	3

***Part-whole correction training (PWCT)*:** PWCT is a combined part correction and whole correction trainings. The objective was to compare the benefit of a combined training program. The participants in PWCT began their training with PCT for 2 weeks followed by WCT for another 2 weeks. The training program is presented in Tables 1 and 2.

***Whole-part correction training (WPCT)*:** In WPCT, the participants started their training with WCT followed by PCT. The workload and exercise intensity between PWCT and WPCT were similar. The only difference was the order of the training program.

Data collection and statistical analysis

SPSS (version 23; IBM, Armonk, NY, USA) was used to conduct all statistical analyses. A mixed-model repeated measures analysis of variance with test (pretest, mid-test, and posttest) as within-subject factors, and intervention (PCT, WCT, PWCT, and WPCT) as between-subject factors was performed to analyze hip strength, and CPDA. The significance level was set at $\alpha = 0.05$. If there was a significant difference between groups, Bonferroni adjustments for multiple comparisons were used for all outcomes.

Results

Table 3. Mean ± SD of participant demographics and baseline VO_2 max in all groups

Variables	PCT (n = 8)	WCT (n = 8)	PWCT (n = 8)	WPCT (n = 8)	Mean ± SD
Age	35.62 ± 5.55	35.50 ± 8.21	36.25 ± 7.46	36.75 ± 7.10	36.03 ± 6.27
Height	159.62 ± 4.80	159.38 ± 4.0	160.19 ± 3.59	158.63 ± 6.39	159.44 ± 4.63
Weight (kg)	52.00 ± 4.47	50.24 ± 2.32	51.48 ± 3.38	51.13 ± 5.09	51.06 ± 4.09
%Body fat	25.88 ± 1.99	25.98 ± 3.36	25.73 ± 2.38	25.74 ± 2.92	25.87 ± 2.91
VO2max (ml/kg/min)	40.63 ± 7.8	40.50 ± 8.6	40.88 ± 7.25	41.38 ± 8.19	40.97 ± 6.79

Table 3 presented means and SDs for all variables. No statistical differences were found between age, height, weight, % body fat and VO_2max among the four groups at baseline (age: $F_{(3,28)} = 0.062$, $p > 0.974$; height: $F_{(3,28)} = 0.133$, $p > 0.939$; weight: $F_{(3,28)} = 1.229$, $p > 0.318$; %body fat: $F_{(3,28)} = 4.732$, $p > 0.009$, and VO_2max: $F_{(3,24)} = 0.023$, $p > 0.995$). As a result, the participants in each group had similar demographical data at pretest.

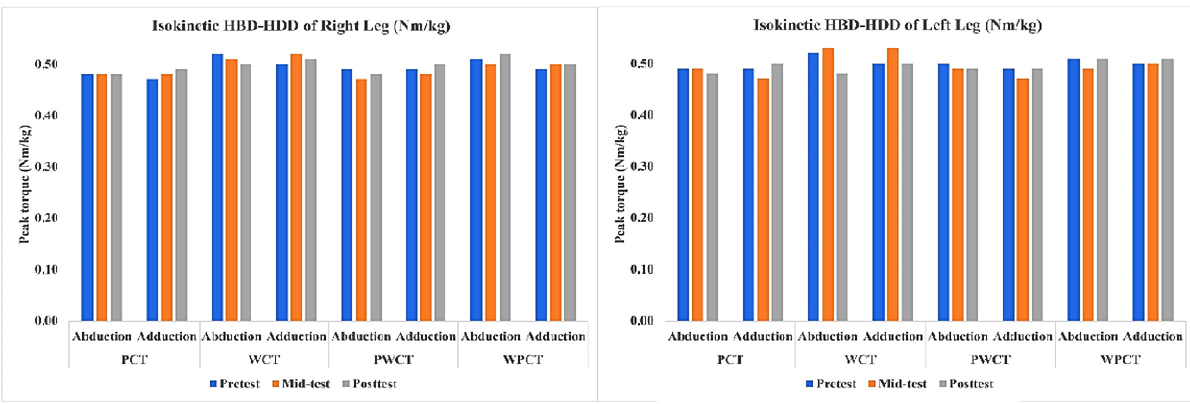

Figure 1. Peak torque of hip abduction-adduction muscle (Nm/kg) during pretest, mid-test and posttest.

Figure 1 shows the isokinetic peak torque of hip HBD-HDD muscle during pretest, midtest, and posttest in all experimental groups. No group × time (4 × 3) interactions were observed for the isokinetic peak torque of hip HBD-HDD muscle, nor were significant main effects for group or time presented in all groups (right HBD; $F_{(6,56)} = 0.559$, $p > 0.761$, *right HDD*; $F_{(6,56)} = 0.512$, $p > 0.797$, *left HBD;* $F_{(6,56)} = 1.139$, $p > 0.352$ *and left HDD;* $F_{(6,56)} = 0.651$, p > 0689*). Thus, our results showed that each training program did not statistically improve peak torque of the hip.*

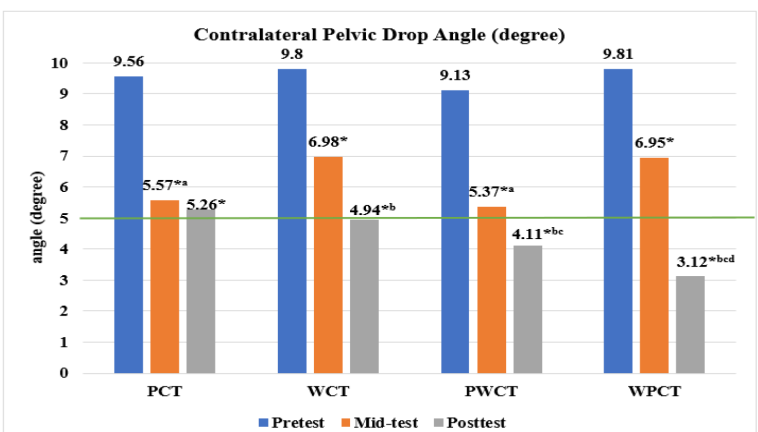

Figure 2. Mean ± SD of contralateral pelvic drop angle during pretest, mid-test and posttest.

A mixed-model ANOVA on CPDA shown in Figure 2, which reveals that the group × time interaction is statistically significant, $F_{(6,56)} = 18.177$, $p < 0.000$. The further evaluation of this interaction indicated that *there was no significant difference between PCT, WCT, PWCT and WPCT groups at pretest.* The Bonferroni-adjusted comparison indicated that, PWCT ($M \pm SD = 5.37 \pm 0.52°$) and PCT ($M \pm SD = 5.57 \pm 0.35°$) reduced in CPDA greater than WPCT ($M \pm SD = 6.95 \pm 0.866°$) and WCT ($M \pm SD = 6.98 \pm 0.96°$) during midtest. After posttest, CPDA in all groups showed a significant difference when compared with that in pretest and midtest, especially in the combined training group. WCT (*M* ± *SD* = 4.93 ± 0.44°) reduced CPDA greater than PCT (*M* ± *SD* = 5.26 ± 0.13°). While PWCT (*M* ± *SD* = 4.27 ± 0.46°) reduced CPDA greater than PCT and WCT. WPCT *(M* ± *SD* = 3.12 ± 0.10°*)* achieved the best reduction in CPDA compared to other groups during posttest.

Furthermore, the obtained result revealed a significant difference in the main effect for the group, $F_{(3,28)} = 10.387$, $p < 0.000$ *and time,* $F_{(2,56)} = 824.154$, $p < 0.000$. *This effect showed CPDA significantly changed over time. Bonferroni adjustments indicated that the significant main effects reflect a significant difference (p < .01) between pretest and midtest, pretest and posttest, and midtest and posttest. Therefore, CPDA reduced in midtest and posttest.*

Discussion

The purpose of this study was to compare the effects of 4-week neuromuscular training programs (PCT, WCT, PWCT, and WPCT) on CPDA during midstance of female runners. Our results supported our hypothesis where a combined correction training significantly reduced CPDA when compared to a single correction training (PCT and WCT). A combined correction training capitalized on the benefits of both PCT and WCT. The combination of both training programs improved both motor acquisition and motor adaptation which are involved in learning new movement patterns (Caramiaux et al., 2020; Magill & Anderson, 2010; Rhein &Vakil, 2018).

Our finding highlighted the importance of the training order in correction training. The obtained results showed that CPDA in WPCT was statistically better than CPDA in PWCT. In WPCT, the participants began their correction training by receiving feedback during running for two weeks before performing SSLS for another two weeks. Since running is a movement activity that the participants normally experienced, receiving feedback during the entire practice (or running) encouraged new cognitive framing and adjustment of motor skills to address CPD (Agresta & Brown, 2015; Davis & Futrell, 2016; Leech et al., 2022). As the audio feedback faded, the participants needed to use the instant visual feedback and the new cognitive framing received from audio feedback to create their own motor strategy to coordinate their muscle movements at the right time to reduce CPD (Leech, Roemmich, Gordon, Reisman, & Cherry-Allen, 2022; Spampinato & Celnik, 2021). After the participants were familiar with their own motor strategy, SSLS specifically focused on existing residual technical errors to help further improve CPD. The participants received specific feedback during SSLS resulting in sensorimotor adaptation and in promoting muscle synergy. SSLS trained the gluteus medius to act as the synergy of hip muscles on the stance leg. Moreover, the training allowed the hip muscles to coactivate to maintain hip level and regulate the pelvic movement in the frontal plane (Hagio & Kouzaki, 2014; Mehrabi et al., 2019)

To limit the possible impact of muscle hypertrophy and to focus mainly on neuromuscular training, our correction training was limited to 4 weeks. Our results showed no significant improvement in muscle strength in gluteal muscles. Therefore, the training program increased neuromuscular responses (e.g., muscular recruitment, synchronization, adaptation of synergist muscles, and/or activation) that benefit the CPD. However, employing electromyography is recommended to understand muscle adaptations during training.

Conclusion

The study findings suggested that the whole-part correction training program was most appropriate for correcting CPDA within a short period of time. The participants utilized whole correction to internalize the concept of whole motion and capitalized on part correction by increasing the interaction of synchronization for simplifying and coordinating muscle activities to mechanically control unstable joints. Our results further highlighted the benefits of deliberate practice where the participants optimally adapted their movement strategy to fix movement mistakes and later memorized the relearned movements to correct the mistakes. Hence, the benefits of training were that CPDA after 1-month follow up marginally differed from that of post-training.

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