EFFECTS OF 4-WEEK NEUROMUSCULAR TRAINING ON CONTRALATERAL PELVIC DROP AND RUNNING ECONOMY IN RECREATIONAL FEMALE RUNNERS

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ผลของโปรแกรมการฝึกระบบประสาทกล้ามเนื้อ 4 สัปดาห์ที่มีต่อภาวะสะโพกตกและประสิทธิภาพการวิ่งในนักวิ่งสมัครเล่นหญิง

น.ส.วีนัส ดอกจันทร์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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Thesis Title	EFFECTS OF 4-WEEK NEUROMUSCULAR TRAINING ON CONTRALATERAL PELVIC DROP AND RUNNING ECONOMY IN RECREATIONAL FEMALE RUNNERS
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Field of Study	Sports Science
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วีนัส ดอกจันทร์ : ผลของโปรแกรมการฝึกระบบประสาทกล้ามเนื้อ 4 สัปดาห์ที่มีต่อภาวะสะโพกตกและประสิทธิภาพการวิ่งในนักวิ่งสมัครเล่นหญิง. (EFFECTS OF 4-WEEK NEUROMUSCULAR TRAINING ON CONTRALATERAL PELVIC DROP AND RUNNING ECONOMY IN RECREATIONAL FEMALE RUNNERS) อ.ที่ปรึกษาหลัก : รศ. ดร.ชัยพัฒน์ หล่อศิริรัตน์, อ.ที่ปรึกษาร่วม : ดร.คาซึโนบุ โอกะซากิ

งานวิจัยนี้มีจุดประสงค์เพื่อศึกษาผลของโปรแกรมการฝึกระบบประสาทกล้ามเนื้อเป็นระยะเวลา 4 สัปดาห์ กลุ่มตัวอย่างเป็นอาสาสมัครนักกีฬาวิ่งระยะไกลสมัครเล่น เพศหญิง จำนวน 32 คน และมีภาวะสะโพกตกขณะวิ่ง งานวิจัยนี้แบ่งออกเป็น 2 การศึกษา โดยการศึกษาที่ 1 เปรียบเทียบผลของโปรแกรมการฝึกระบบประสาทกล้ามเนื้อด้วยโปรแกรมการฝึก 4 รูปแบบ เพื่อหาโปรแกรมที่มีประสิทธิภาพในแก้ไขภาวะสะโพกตกและประสิทธิภาพการวิ่ง และการศึกษาที่ 2 เพื่อศึกษาผลของการคงอยู่ของทักษะหลังการฝึกด้วยโปรแกรมทั้ง 4 รูปแบบ การศึกษาผลของโปรแกรมการฝึกระบบประสาทกล้ามเนื้อ 4 สัปดาห์ กลุ่มตัวอย่างถูกแบ่งออกเป็น 4 กลุ่ม โดยกลุ่มที่ 1 ทำการฝึกแก้ไขแบบแยกส่วนด้วยท่าฝึกก้าวสควอทขาเดียว กลุ่มที่ 2 ทำการฝึกแก้ไขแบบรวมด้วยการฝึกวิ่ง กลุ่มที่ 3 ทำการฝึกผสมผสานแบบแยกส่วนตามด้วยการฝึกแบบรวมด้วยการฝึกก้าวสควอทขาเดียวใน 2 สัปดาห์แรกและฝึกด้วยการวิ่งใน 2 สัปดาห์หลัง และกลุ่มที่ 4 ทำการฝึกผสมผสานแบบรวมตามด้วยการฝึกแบบแยกส่วนทำการฝึกด้วยการวิ่งใน 2 สัปดาห์แรกและตามด้วยการฝึกก้าวสควอทขาเดียวใน 2 สัปดาห์ ทำการทดสอบหามุมของสะโพกตกด้วยการทดสอบการวิเคราะห์การเคลื่อนไหว 3 มิติและทดสอบประสิทธิภาพการวิ่งด้วยการวิเคราะห์แก๊ส จากนั้นทำการวิเคราะห์ความแปรปรวนแบบผสมชนิดวัดซ้ำและเปรียบเทียบรายคู่ด้วยวิธีแบบ Bonferroni กำหนดความมีนัยสำคัญทางสถิติที่ระดับ .05 ผลการวิจัยพบว่ามีปฏิสัมพันธ์ระหว่างกลุ่มและเวลาในการทดสอบมุมภาวะสะโพกตกอย่างมีนัยสำคัญทางสถิติ ในขณะที่ประสิทธิภาพของการวิ่งมีค่าไม่แตกต่างกันในทุกกลุ่มอย่างมีนัยสำคัญทางทางสถิติ การศึกษาผลของการคงอยู่หลังการฝึก 4 สัปดาห์ในการศึกษาที่ 2 ผู้วิจัยใช้การทดสอบด้วยวิธีการทดสอบเดิมหลังผู้เข้าร่วมการวิจัยไม่ได้รับการฝึก 4 สัปดาห์ พบว่ามุมขอองภาวะสะโพกมีค่าไม่แตกต่างกันในทุกกลุ่มเมื่อเปรียบเทียบกับการทดสอบหลังการฝึก 4 สัปดาห์

สรุปผลการวิจัยพบว่าการฝึกระบบประสาทกล้ามเนื้อแบบผสมผสานการฝึกรวมตามด้วยการฝึกแบบแยกส่วน (Whole-Part correction training) เป็นเวลา 4 สัปดาห์ ส่งผลต่อการลดมุมของภาวะสะโพกตกในขณะวิ่งได้ดีที่สุด อีกทั้งการฝึกระบบประสาทกล้ามเนื้อทำให้เกิดการเรียนรู้จดจำและนำมาปรับใช้จริงในขณะที่ได้กลับมาทำทักษะเดิมหลังการทดสอบหลังการฝึกเป็นเวลา 1 เดือน

สาขาวิชา	วิทยาศาสตร์การกีฬา	ลายมือชื่อนิสิต ....
ปีการศึกษา	2564	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....
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KEYWORD: contralateral pelvic drop, running economy, neuromuscular training, recreational female runner, whole practice, part practice

Venus Dokchan : EFFECTS OF 4-WEEK NEUROMUSCULAR TRAINING ON CONTRALATERAL PELVIC DROP AND RUNNING ECONOMY IN RECREATIONAL FEMALE RUNNERS. Advisor: Assoc. Prof. CHAIPAT LAWSIRIRAT, Ph.D. Co-advisor: Prof. Kazunobu Okazaki, Ph.D.

The purpose of this study was to investigate the effects of 4-weeks neuromuscular training programs on contralateral pelvic drop (CPD) and running economy (RE) in female runners. Thirty-two female runners who experienced CPD volunteered for the study. The study was divided into 2 parts. The first part investigated the effectiveness of four neuromuscular training programs during four weeks. The purpose of the first part was to find which neuromuscular training program was most effective in correcting CPD. The second part examined the retention effects of the four neuromuscular training programs for another four weeks. In this study, the participants were divided into 4 groups of eight participants. The first groups received part correction training (PCT) where the participants received audio and visual feedbacks during step single leg squat (SSLS), while the second group performed whole correction training (WCT) where the participants received audio and visual feedbacks during running. The third group performed part whole correction training (PWCT) where they began the training with SSLS for 2 weeks followed by running for the last two weeks. The last group performed whole part correction training (WPCT) where they began their training by running before SSLS. The participants were assessed for contralateral pelvic drop angle (CPDA) and running economy (RE). CPDA was assessed during stance phase using 3D motion analysis, while RE was assessed using incremental running test. A mixed model ANOVA was performed to investigate the effects among the four neuromuscular trainings. The level of significance was set at 0.05. The results showed that the group x time interaction was statistically significant in CPDA while no statistical differences were found among four groups in RE. The comparison of retention effect of neuromuscular training program in study 2 was reassessed for 1 month. The testing procedure was identical to the first study. After 1-month follow up, we found no statistical differences in CPDA within-group of all groups. The results indicated that the participants in all groups were able to modify motor behavior and retain their improved skills after 1-month training

Further analysis suggested that WPCT was the most effective program in addressing CPDA during 4-week training. Moreover, the neuromuscular training program were able to modify the motor behavior and retain skill after 1-month training.

Field of Study:	Sports Science	Student's Signature ....
Academic Year:	2021	Advisor's Signature ....
		Co-advisor's Signature ....

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CHAPTER I

INTRODUCTION

Background and Rationale

Running is one of the most popular regular cardiovascular exercises and practiced sports worldwide. It is an endurance sport. Many people practice running at both competitive and recreational levels. As running requires runners to perform repeated movements for a long duration. To achieve maximum performance, runners need to have not only good cardiovascular fitness but also biomechanical and neuromuscular efficiency Cardiovascular fitness is the ability to provide the required energy for the specific tasks in which the cardiopulmonary system adequately supplies the consumed oxygen to working muscles (Saunders, Pyne, Telford, & Hawley, 2004). Biomechanical and neuromuscular efficiency pertains to performance techniques allowing athletes to achieve the best outcome with relatively less physiological demands than other runners.

Running mechanics associates with braking forces and vertical oscillation. The mechanics of running are divided into 2 phases: flight and stance phase. The flight phase is the time when no limbs are touching the ground and, thus, no external force is applied to the body. The stance phase is the time when one limb is in contact with the ground (Tongen & Wunderlich, 2010). In the stance phase, the foot starts to contact the ground. At this instant, the body weight is being supported on one leg (loading absorption). As the foot continues to contact the ground, the center of mass moves from heel to toe (mid stance) resulting in the stretching of lower limb joints to push the body forward (propulsion). Once the foot takes off the ground, the swing phase begins.

During midstance, runners start to push their body forward by producing maximum vertical ground reaction force (VGRF) at approximately 2.2-2.6 times body weight in distance runners (J. Dicharry, 2010). At this instant, the hip ipsilateral to the ground-contacted foot will be adducted. The contralateral pelvis will, therefore, be lower making the lumbar spine slightly bend to the same side of the ground-contacted foot. As a result, the hip abductor plays an important role in lower extremity stability. A weak hip abductor cannot produce sufficient torque to prevent excessive femoral adduction and hip internal rotation leading to the contralateral pelvic (Dunphy, Casey, Lomond, & Rutherford, 2016). These simultaneous movements among the hip, pelvic, and lumbar spine provide stability to the runners. Mismanagement of hip, pelvic, and lumbar spine movements results in poor running techniques, inefficiency, and unnecessary waste of energy.

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) and is found to be one of the leading indicators to identify runners with injuries. Bramah, Preece, Gill, and Herrington (2018) showed that every 1-degree increase in pelvic drop resulted in more chances of injuries by 80 percent. Furthermore, CPD is more commonly found in female runners than male runners. Female runners have a 5.3 times higher risk of suffering from running related injury related to CPD than male runners (Ireland, Durbin, & Bolgla, 2012).

CPD causes an imbalance in the body's shock absorption which affects running mechanics and performances. Runners with CPD usually exhibit femoral internal rotation, knee adduction/valgus, excessive tibial internal rotation, and excessive foot pronation (Powers, 2003). These symptoms lead to increases in peak knee adduction moment (KAM). As KAM increases, runners demonstrate greater CPD angle (Dunphy et al., 2016) and muscle stiffness (Jaén-Carrillo et al., 2021; Kito et al., 2010). Higher muscle stiffness prevents runners from achieving suitable flexion and poor alignment in hip, knee, and ankle joints, leading to insufficient propulsive force production, a decrease in body's shock absorption and an increase in impact force on the lower extremity joints (Brughelli & Cronin, 2008; Jaén-Carrillo et al., 2021; Kito et al., 2010).

Studies showed weaknesses in hip abductor could contribute to CPD (Cashman, 2012; Claiborne, Armstrong, Gandhi, & Pincivero, 2006; Jacobs, Uhl, Mattacola, Shapiro, & Rayens, 2007; Willson, Petrowitz, Butler, & Kernozek, 2012). Weak hip abductor muscles make it difficult for runners to support their weight during running. As a result, the center of mass moves away from the stance leg and, thus, increasing the frontal plane lever arm of ground reaction force and knee adduction moment (KAM) (Chang et al., 2015). While many researches believed that weaknesses in hip abductor caused CPD, several researches found no improvement of CPD after hip abductor strengthening program (Fields, 2011; Heiderscheit, 2010; Hollman et al., 2009; Niemuth, Johnson, Myers, & Thieman, 2005). Willy and Davis (2011) discovered that the hip angle was improved from a single leg squat training program, and further suggested the improvement of CPD may be due to neuromuscular training to help improve movement adaptation for runner.

Neuromuscular training (NT) is an exercise program which aims to improve motor responses and enhance nervous system's capacity in order to relearn movement patterns and abilities. The relearned movements usually aim for better dynamic joint stability and a reduction of joint forces (Risberg, Mørk, Jenssen, & Holm, 2001). NT capitalizes on verbal feedbacks and, sometimes, visual feedbacks to let participants acknowledge their movement inefficiency and improve or correct the inefficient movements by focusing their attention to 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.

NT has been found to improve CPD as well as reduce injuries related to running. Researchers found several running improvements after NT programs. NT programs were found to effectively increase muscular recruitment and postural stability (McKeon et al., 2008; O'Driscoll & Delahunt, 2011), gait kinematics (McKeon et al., 2008), and movement pattern in different groups, such as patients with ankle injury and anterior cruciate ligament repair (Hewett, Ford, & Myer, 2006; McKeon et al., 2008). The benefits of NT also included reductions of KAM, CPD, horizontal pelvic velocity, ground reaction force (GRF), knee flexion-extension ROM, and hip abduction/adduction ROM, stride rate, while increasing leg stiffness and stride length

The effectiveness of NT depends on the complexity of movement tasks, the ability to adapt and relearn motor skills of participants, the ability to interpret and process verbal and/or visual instructions, as well as, how 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, hence, is easily interpret and address. In contrast to only focusing attention to one specific skill, whole correction technique concentrates on entire movement. Thus, given instruction is relatively less concise and more difficult to interpret and address. However, participants would have a better understanding and appreciation of the kinesthetic principle of the entire movement process (Magill & Anderson, 2010; Park, Wilde, & Shea, 2004). Moreover, studies suggested whole correction technique was effective for movements with high interlimb coordination (Fontana, Furtado Jr, Mazzardo, & Gallagher, 2009; Swinnen & Carson, 2002; Wenderoth, Puttemans, Vangheluwe, & Swinnen, 2003). Both techniques have been found to improve running movements. To the best of our knowledge, no research has address compared the effectiveness between these two correction techniques.

Therefore, the purpose of this paper was to compare the effects of neuromuscular training program among part correction training, whole correction training, a combined part-whole correction training and a combined whole-part correction training during four weeks of exercise. It was hypothesized that a combined part-whole correction training was more effective. Based on Fitt & Posner's theory (1967), motor skills can be perfected by starting from a sequential simple task where participants utilize their cognitive function to control the sequential simple task before advancing to more complex and fluid movement tasks until the participants can automatically perform the intended motor skills. The results of the thesis provide insights and highlights on which training methods should be used to minimize training period while maximizing running performance.

RESEARCH QUESTIONS

Study I

Are there any differences between effects of neuromuscular training program among part correction training, whole correction training, a combined part-whole correction training and a combined whole-part correction training on contralateral pelvic drop and running economy in long-distance recreational female runners?

Study II

Are there any differences in the retention effects of neuromuscular training program among part correction training, whole correction training, a combined part-whole correction training and a combined whole-part correction training on contralateral pelvic drop and running economy in long-distance recreational female runners?

RESEARCH HYPOTHESIS

1. The contralateral pelvic drop angle of combined correction training was lower than a single correction training, while the running economy of whole correction training group is better than part correction training group.

2. The contralateral pelvic drop angle of a combined part-whole correction training was lower than the whole-part correction training.

3. The participants in a combined part-whole correction training can maintain the level of hip and has a better running economy than other groups during the 1^{st}, $2^{nd}$and 4^{th} week of the retention phase.

PURPOSES OF THE STUDY

Primary purposes

To compare the effects of neuromuscular training program among part correction training, whole correction training, a combined part-whole correction training and a combined whole-part correction training during four weeks of exercise in long-distance recreational female runners.

Secondary purpose

To compare the retention of whole correction training, part correction training and the combination of sequence on contralateral pelvic drop and running economy in long-distance recreational female runners.

SCOPE OF THE STUDY

This study was the experimental research that prospectively discovers the suitable training method for correcting the contralateral pelvic drop in long-distance recreational female runners. The study was divided into 2 studies. **The study 1** of the research compared the effects of whole correction training, part correction training and the combination of sequence on contralateral pelvic drop and running economy in long-distance recreational female runners, and **study 2** of the research compared the retention of whole correction training, part correction training and the combination of sequence on contralateral pelvic drop and running economy in long-distance recreational female runners.

STUDY 1

The purpose of this study was to compare the effects of neuromuscular training program among part correction training, whole correction training, a combined part-whole correction training and a combined whole-part correction training on contralateral pelvic drop and running economy in long-distance recreational female runners.

1. Participants

Thirty-two long-distance recreational female runners volunteered to participate in this study. To participate in the study, the participants were required to pass the following inclusion criteria: 1) female runners age between 24 and 45 years old with heel strike running pattern. 2) leg length difference was not over 1.5 cm. 3) the participants had no musculoskeletal disease, recent history of musculoskeletal injury and lower limb and back surgery within the past year, and (4) participants exhibited positive of dynamic pelvic drop test. (Appendix C). They were randomized into 4 groups.

- Group 1: Part correction training (PCT; n=8)
- Group 2: Whole correction training (WCT; n=8)

- Group 3: Part followed by whole correction training (PWCT; n=8)
- Group 4: Whole followed by part correction t training (WPCT; n=8)

2. Variables

2.1 Independent variables

2.1.1 Part correction training (PCT) was a training program used to modify movement patterns with “step single leg squat” that were consistent with required movements. The subjects received visual or auditory external feedback. The part correction training of this study would be training for 4 days/week for a total duration of 4 weeks.

2.1.2. Whole correction training (WCT) was a training program used to modify running mechanics or techniques for a better form and to reduce the stress of the joint through receiving visual or auditory external feedback. Whole correction training of this study would be training for 4 days/week for a total duration of 4 weeks.

2.1.3 Part followed by whole correction training (PWCT) was similar to the previous group, but the subjects begun their training with part correction training 4 days/week for two weeks followed by whole correction training 4 days/week for two weeks.

2.1.4 Whole followed by part correction training (WPCT) was a combination of whole correction training and part correction training where subjects begun their training with whole correction training 4 days/week for two weeks followed by part correction training 4 days/week for two weeks.

2.2 Dependent Variables

2.2.1 The contralateral pelvic drop angle during the midstance of stance phase. The participants performed a 5-minute running as a warm-up. After that, they were instructed to run on a treadmill for 18 minutes where the participants ran for 6 minutes at 65% of velocity at VO_2max before running for 6 minutes at 75% and another 6 minutes running at 85%, respectively. The test procedure was similar to Fletcher et al (2009). Data during the stance phase of the last 6 minutes were collected to compute CPD angle because 85% of velocity at VO_2max was a sub-maximal speed the participants were able to maintain. The stance phase happened 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 in one minute. As a result, 72 CPD data points were collected into Visual 3D (C-Motion, Inc, Rockville, MD) and MATLAB software (Mathworks, Inc., Natick, MA). To calculate CPD angle, a vector calculation similar to Huntington (2018) was employed where CPD was an angle between pelvic plane and a transverse plane. The pelvic plane was found from Sacrum, left ASIS and right ASIS. CPD angles were measured in degree, and the average value of CPD was used to further statistical analysis. The participants had a 10-minute rest before proceeding to RE test.

2.2.2 Running Economy was measured by adapting the protocol used by (Fletcher, Esau, & MacIntosh, 2009). After the participants were equipped with a gas analyzer (Pluto med, H/P cosmos, Germany), the participants performed a warm-up by running at speed of 6 km/hr for 5 minutes. After warm-up, the participants ran for 6 minutes at 65% of velocity at VO_2max before running for 6 minutes at 75% and another 6 minutes running at 85%, respectively. The breath-by-breath VO_2 was averaged every 30-second. The average rate of O_2 consumption of the last two minutes when the participants ran at 85% of velocity at VO_2max was used to evaluate running economy.
RE was calculated using the following formula (Skovgaard et al., 2018):

$$\text{RE (mL } O_2\text{/kg/km)} = \frac{\text{VO2 (mL/min) x 60 min/h}}{\text{Bm (kg)x running speed (km/h)}}$$

where VO_2 was the average value during the last 2 minutes of running for the speed at 85% vVO_2max, and BM was the body mass.

2.2.3 Lever arm length of hip adduction moment by adapting the calculation used by Jenkyn, Hunt, Jones, Giffin, and Birmingham (2008) was employed where the frontal-plane lever arm is the perpendicular distance from the marker on the heel to the marker on the ASIS of the contralateral pelvic dropped side. On average, there were 12 running cycles in one minute, As a result, 72 lever arm length data points were collected into Visual 3D (C-Motion, Inc, Rockville, MD) and MATLAB software

(Mathworks, Inc., Natick, MA). Marker trajectories data were low pass filtered at 10 Hz using 4th order Butterworth filter.

2.3 Control Variable

Control variable was the strength of hip abductor-adductor muscle, which would be examined by the isokinetic test of hip muscle before and after training. However, the designed whole correction training and part correction training was expected not to affect the potential influence of hypertrophic muscle changes on running mechanics due to short period of training.

STUDY 2

The study compared the retention of the research compared the retention of whole correction training, part correction training and the combination of sequence on contralateral pelvic drop and running economy in long-distance recreational female runners. The retention duration is divided into 3 follow ups, which are 1st week follow up, 2nd week follow up and 4th week follow up. All the retention duration will examine for 4 weeks.

1. Participants

Thirty-two long-distance recreational female runners volunteered to participate in this study. To participate in the study, the participants were required to pass the following inclusion criteria: 1) female runners age between 24 and 45 years old with heel strike running pattern. 2) leg length difference was not over 1.5 cm. 3) the participants had no musculoskeletal disease, recent history of musculoskeletal injury and lower limb and back surgery within the past year, and (4) participants exhibited positive of dynamic pelvic drop test. (Appendix C). They were randomized into 4 groups.

- Group 1: Part correction training (PCT; n=8)
- Group 2: Whole correction training (WCT; n=8)
- Group 3: Part followed by whole correction training (PWCT; n=8)
- Group 4: Whole followed by part correction t training (WPCT; n=8)

2. Variables

2.1 Independent variables

The independent variables were four training programs that we conducted during the study 1 (e.g., Part correction training, Whole correction training, Part followed by whole correction training and whole followed by part correction t training).

2.2 Dependent Variables

The dependent variables were contralateral pelvic drop angle, running economy, and lever arm length that we conducted during the study 1.

2.3 Control Variable

Control variable was the strength of hip abductor-adductor muscle, which would be examined by the isokinetic test of hip muscle before and after training. However, the designed whole correction training and part correction training was expected not to affect the potential influence of hypertrophic muscle changes on running mechanics due to short period of training.

DEFINITION OF TERMS

1. Long-distance recreational runner means a person who usually runs practices running regularly, usually, run longer than 10 km/week but less than 30 km/week.

2. Whole correction training means a training pattern used to modify movement mechanics or techniques of runners through receiving visual and auditory external feedback. The whole practice for correcting the posture of contralateral pelvic drop in their actual running with the feedback and watch the monitor for checking their position.

3. Part correction training means a training pattern used to modify movement patterns with step single leg squat that has the movement similar to single-limb support action of the stance phase during running. The step single leg squat is used in the part correction technique (part practice) for correcting the posture of contralateral pelvic drop that are consistent with required movements to be trained including receiving visual and auditory external feedback.

4. Contralateral pelvic drop (CPD) means the opposite hip to the weight-bearing leg is lower than the hip of the weight-bearing leg when measured in the frontal-back plane. The degree of peck pelvis obliquity during midstance of stance phase. The degree of

peck pelvis obliquity during midstance of stance phase. Mid stance is the point at which the bodyweight is directly over the supporting lower extremity. The angle of pelvic obliquity was measured when the marker on the Lateral Malleolus of the swinging leg was parallel with the marker on the Lateral Malleolus of the stance leg.

5. **Running Economy** means the energy spend when running at a speed lower than the maximum speed in running (submaximal speed) (Barnes & Kilding, 2015).

6. **Retention** means the ability to recall previous external feedback of movement correction and be able to apply to the running automatically (Magill & Anderson, 2010).

7. **Maximum oxygen uptake (VO_2max)** means a fundamental measurement for the exercise physiologist. VO2max refers to the highest rate at which oxygen can be taken up and consumed by the body during intense exercise (Bassett et al., 2000).

8. **Pat followed by whole correction training** means the training method that use step single leg squat to fix the one leg stance movement in midstance phase in order to correct pelvic obliquity during the first 2 weeks. The step single leg squat is part-training movement which subjects can focus on one task while receiving feedback. In the last 2 weeks, the whole correction training aims to correct the whole process of running mechanics through series of feedback while subjects to perform an actual running.

The sequence that begins with a simple movement of part correction training, which in this case is a step single leg squat, then followed by a more complex movement of whole correction training (Herman et al., 2009).

9. **Whole followed by part correction training** means the training method that use the whole correction training to correct the whole process of running mechanics through series of feedback in the first 2 weeks. Then followed by part correction training in last 2 weeks. The part correction training is the training method that use step single leg squat to fix the one leg stance movement in midstance phase in order to correct pelvic obliquity.

CHAPTER 2

LITERATURES REVIEWS

The purposes of the research were to compare the effects of part correction training, whole correction training, part correction training followed by whole correction training and whole correction training followed by part correction training. Furthermore, this research will also study the retention of all training programs that affect contralateral pelvic drop and running economy in long-distance recreational female runners. Many important summaries of reviewing literature are concluded for utilizing as a guideline for research studies, with topics as follows.

1. Running
    1.1 Long-distance recreational female runner
    1.2 Running biomechanics
    1.3 Running kinematics
    1.4 Muscle activation patterns during running
2. Contralateral pelvic drop
    2.1 Hip anatomy and muscle
    2.2 Hip biomechanics
    2.3 Forces acting on the hip
    2.4 Contributed factors of contralateral pelvic drop
3. Running economy
    3.1 Biomechanical factors affecting running Economy
    3.2 Factors affecting running economy
4. Neuromuscular training
    4.1 Neuromuscular training alters running biomechanics
    4.2 Single leg squat (SLS)
    4.3 Neuromuscular reeducation fundamental
    4.4 Fitt & Posner (3 stages of learning)
    4.5 Motor skill learning and practice application

Related literature

1. RUNNING

1.1 LONG-DISTANCE RECREATIONL FEMALE RUNNER

The most popular sporting and recreational activities in the world is running. Long-distance running is running over a distance of at least 3 kilometers (1.8 miles), up to a marathon (42.195 kilometers) continuely (Federations, 2018; IAAF, 2014).The long-distance runners have progressively conditioned their bodies over many years to tolerate an incredibly high volume of training, over 200 kilometers/week. According to the retrospective study stuied 1,819 injuries in 1, 650 runners (Macintyre et al., 1991). Runners were classified as middle-distance, marathon, and recreational runners, and further grouped by gender. Middle-distance runners were elite runners training for races at the distances of 800 to 5,000 meters. Marathon runners were the runners completing high mileage and who ran at least one marathon per year. Lastly, recreational runners were the runners who choose running as their primary sport and participated in much lower weekly mileage.

Researchers utilize these classifications as a means of drawing comparisons amongst the wide variety, whereas runners use these terms to distinguish or identify themselves to other runners. For example, runners have been classified as beginner, intermediate, and advanced, or also as a novice, recreational and competitive, both groupings being based on either experience or by race pace. However, one classification incorporates multiple components including miles per week, race history, involvement in running subculture, and reason for participation. This classification is greatly beneficial when classifying recreational runners as individuals report a wide variety of reasons for choosing to participate in running. Via this classification system, runners can be classified as:

1. Full-time runner: Runs more than 40 miles per week, is heavily involved in racing, most new friends are runners, immersed in running subculture, and running literature occupies their time weekly.

2. Part-time runner: Runs 11 to 40+ miles per week, heavily involved in racing but less involved in running subculture, competitive runners with talent that will continually reinforce efforts at improvement.

3. Hobby runner: Runs 11 to 40+ miles per week, rarely races, subculture and race performance are not important, expects no payback other than the joy of participation.

4. Occasional runner: Runs 4 to 24+ miles per week, runs at least one day per week, running either tapers or stops during winter months.

Middle- and long-distance running events are popular in organized sports all around the world. M/L running competitions include anything from 800-meter track races to marathons and cross-country. Elite runners with heavy training loads might run up to 35 hours per week in the weeks leading up to a major competition. Intense training regimens and several competitive events spread across the athletic calendar may put a lot of strain on an athlete's body. As a result, high-level runners are susceptible to musculoskeletal problems that can be severe enough to render them disabled. Authors have reported an injury prevalence percentage of 43-76 percent among athletes across all athletic disciplines, however studies looking at the incidence of injuries over the course of a full sports season found that two out of every three athletes incur injuries on a yearly basis (Johansen, Hulme, Damsted, Ramskov, & Nielsen, 2017).

1.2 RUNNING BIOMECHANICS

Nicola and Jewison (2012) described the running biomechanics relates to the structure, function, and capabilities of the lower extremities and entire kinetic chain that enable a human to run. Although no two people have the same anatomy, strength, or proprioceptive abilities, there are many commonalities to grasp about the function of each individual's running cycle in diagnosing and treating running injuries. The anatomy of the lower extremity as it pertains to the ability to run, the running gait cycle, and aberrant anatomy and biomechanics associated to running injuries are all covered in this article.

The gait cycle of walking varies from that of running. Between the first impact of the foot with the surface and its reconnection with the surface at the end of the cycle, the gait cycle is described as a sequence of motions of the lower extremities. The stance phase and the swing phase make up the gait cycle. When the foot makes contact with the running or walking surface, this is known as the stance phase. When walking or running, these phases are visible. When one lower extremity is in the stance phase and the other is in the swing phase, the swing phase begins. Running differs from walking in that it contains two float/flight phases. Between the stance and swing phases, there is a float phase in which neither lower extremity makes contact with the ground. As a result, throughout the gait cycle, running at any speed may be defined as either 1 leg striking the ground or no leg striking the ground (Jay Dicharry, 2010).

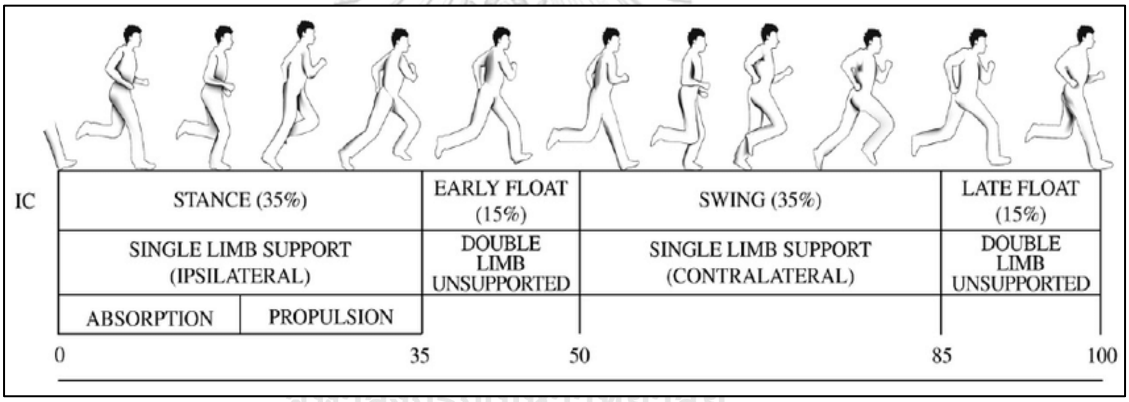


Figure 1 The phases of the running stride

Source: Lohman, Balan Sackiriyas, and Swen (2011)

STANCE PHASE

The stance phase begins with foot-strike, midstance and take-off. In each of these activities, different muscle groups, bones, and joints play a distinct role. The muscles, tendons, bones, and joints of the foot and lower leg operate to absorb the shock of the landing at the start of foot strike. The activities of the subtalar joint, a multiplanar joint that generates pronation of the foot, aid in landing during foot-strike. Furthermore, the plantar fascia expands to allow the foot to expand and absorb the impact of landing. Dorsiflexion occurs at the talocrural ankle, and is accompanied by knee flexion and hip motion, all of which contribute to the distribution of impact force across the closed kinetic chain that occurs during foot-strike. The energy of impact is transferred from distal to proximal through the rectus femoris and gastrocnemius (ankle to knee to hip). These aid in the distribution of landing force, or shock absorption, across the foot and up the kinetic chain. During push off, this pattern of muscular contractions reverses from proximal to distal. In addition, current study has discovered that the kinematics and stress attenuation capabilities of the lower extremity muscles do not alter with running-related soreness. In preparation for take-off, the foot begins to transition from pronation to supination as the stance phase continues to midstance. As the leg moves during the stance phase, the hamstrings shorten and contract. The contraction and push-off motion performed by the gastrocnemius, soleus, and Achilles tendon cause plantar flexion of the ankle and enable for take-off or toe-off. This is the start of the swing phase. Before we go into the swing phase, let's take a closer look at the foot-strike.

There are several foot-strike patterns. Heel-strike is one pattern. When the foot is supinated, the lateral heel usually contacts the ground. At heel-strike, the calcaneus is somewhat inverted. This also happens when the heel touches the ground first. Another type of foot-strike is midfoot strike, which can occur in either heel or forefoot strike. Runners that run barefoot often land on their forefoot during the running cycle. Runners who use running shoes on a regular basis, on the other hand, tend to land on their heels upon foot-strike. Pronators begin on the outside of the heel and terminate in the mid to medial forefoot. Supinator will conclude the stance phase on the lateral forefoot and, if forefoot strikers, may not even produce considerable heel wear.

SWING PHASE

The swing phase of the running gait cycle occurs when the lower extremity swings through the air from take-off to foot-strike. This comprises of a follow through, forward swing, and foot fall, followed by a foot-strike that restarts the stance phase. The rectus femoris and anterior tibialis muscles are the most active during take-off. During the late swing phase, the hamstrings and hip extensors are engaged. From late swing through the middle of the stance phase, the hamstrings, gastric-soleus complex, and hip extensors are involved. The float phase comprises forward rotation of the ipsilateral pelvis and hip flexion induced by the psoas and other pelvic muscles, as well as core activation to facilitate pelvic twisting. During the swing phase, the rectus femoris is active. During late swing, the quadriceps begin to contract. The hamstrings stretch as the lower leg extends at the knee, and they are most vulnerable to damage near the conclusion of the swing. The foot begins to descend to the running surface. At this point, the opposing leg is nearing the end of its stance phase. The adductors are engaged throughout the running gait cycle, in both the stance and swing phases.

The KINETIC CHAIN OF RUNNING

In the running gait cycle, the foot and ankle, knee, hip, pelvis, torso, and upper body all play a part. During the running gait cycle, pronation and supination cause numerous modifications across the kinetic chain. The forefoot abducts, the subtalar joint everts, and the ankle (talocrural) joint dorsiflexes and internally rotates the tibia when pronation occurs. In a flexed and valgus posture, the knee follows. This leads to hip flexion, adduction, and internal rotation. When this occurs, the ipsilateral pelvis rotates anteriorly and elevates to rotate forward on the side of pronation (Dugan & Bhat, 2005). Finally, the lumbosacral spine ipsilaterally stretches and flexes. The kinetic chain is activated during the start and midstance phases of the running gait cycle. Supination has numerous consequences throughout the kinetic chain. Supination inverts the subtalar joint, adducts the forefoot, plantarflexes the ankle (talocrural) joint, and externally rotates the tibia. The knee is currently extended in a varus posture. Hip extension, abduction, and external rotation result from this. On the supination side, the pelvis rotates posteriorly and depresses. Finally, the lumbosacral joint expands and flexes laterally away from the supination side. (J. Dicharry, 2010; Dugan & Bhat, 2005). This series of events marks the beginning of the swing stage of the running gait cycle.

1.3 RUNNING KINEMATICS

During running, the most movement occurs in the sagittal plane at the trunk and lower extremity joints, with less movement occurring in the frontal and transverse planes. Running gait has a larger range of motion than walking stride. To distinguish motions when running, it is best to examine kinematics at each individual joint.

TORSO/TRUNK KINEMATICS

Hip and lower extremity movement throughout the running cycle necessitates a solid and robust core muscle group to allow for mobility and limit injury. The ribs, sternum, thoracic and lumbar vertebrae, as well as supporting ligaments and muscles, make up the dynamic components of the upper torso. The "core" muscles absorb and disperse impact stresses, allowing for more controlled and efficient movement. The core muscles are a collection of 29 muscles that support the spine, pelvis, and kinetic chain. During running, trunk flexion ranges between 3° and 13° (Schache, Bennell, Blanch, & Wrigley, 1999). During the running cycle, the trunk is slightly flexed and at its most upright position during foot-strike. The leg subsequently continues to flex throughout the stance period, achieving maximum flexion at the conclusion. The trunk ipsilateral tilt after foot striking has been measured to range from 5° to 20° in synchrony with the pelvic downward tilt (toward contralateral side). Increased speed caused a lateral tilt increase of up to 10 degrees. The thoracic muscles support the spine and abdomen around the axis of the vertebrae as the pelvis rotates with each step.

HIP KINEMATICS

During the running gait, the hip flexes during the swing phase and extends during the stance phase. During the stance phase, the hip adducts, and during the swing phase, it abducts. Swing phase begins with the psoas muscle driving the thigh forward. During the second part of the swing phase and the beginning of the stance phase, the hamstrings and gluteus maximus create power. The hamstrings and hip extensors are particularly active at this time. During single leg support, the abductors and adductors of the hip provide co-contraction stability of the stance leg (stance phase). As velocity rises, the hip increases its flexion range of motion. At foot-strike, the hip can be flexed up to 65° in swing phase and extend to 11° (Schache et al., 1999).

These maximum angles vary depending on the individual and the speed at which they run. The hamstrings and gluteus maximus stretch the hip in the midst of the swing phase to "pull" the body forward. The gluteus maximus helps the hip reach its maximum extension at toe-off. In order to plant the foot under the center of gravity, the hip must extend late in the swing phase. This varies according on the runner. In recreational runners, the hip may move across a range of around 40 degrees, from complete flexion to full extension. In the review by (J. Dicharry, 2010), hip flexion and extension arc can be as much as 60°. This mainly occurs in the sagittal plane of the body. In addition, the amount of extension in the hip decreases slightly as velocity increases. Hip adductor muscles are active throughout the running gait cycle. This is unique from the walking gait cycle in which they are only active from swing phase to the middle of stance phase. Hip abduction-adduction arc can be as much as 15°.

Frontal plane hip abduction/adduction depicts pelvic motion during running. At first foot contact, males have roughly 7 degrees of hip adduction and females have 11 degrees (Willy & Davis, 2011). From foot contact through mid-support the hip abducts slightly reaching a position of hip abduction at take-off. During swing phase a maximum hip abduction angle of 8 degrees is reached; however, this returns to neutral at the time of foot descent before the next foot contact. Internal and external rotation of the hip is minimal during running (Loudon & Reiman, 2012). At initial foot contact the hip is in slight external rotation and moves into hip internal rotation through mid-support phase. From mid-stance to take off the hip internally rotates to a point of neutral hip (0 degrees rotation) at take-off.

PELVIS KINEMATICS

The pelvis, sacrum, and lumbar vertebrae provide support, allowing the extremities to move freely. During the running cycle, the pelvis relies on symmetry to operate. The pelvic axes of motion are rotating, anterior-posterior, and medio-lateral. Excessive anterior pelvic tilt, excessive lateral tilt, and asymmetric hip movement are the most common pelvic biomechanical problems in runners. This incorrect pelvic alignment can also put undue strain on the hamstrings, increasing the likelihood of injury (Dugan &

Bhat, 2005). Injuries can also be caused by abnormal pelvic mechanics. During running, the normal range of motion for flexion and extension inside the pelvis is between 5° and 7°. Running causes a larger anterior pelvic tilt than walking, which helps to enhance stride length. Running results in a net pelvic tilt of 10° to 15°, whereas standing results in a tilt of around 10°. The degree of pelvic tilt changes just slightly as running speed increases. During the single leg stance phase of the running cycle, the gluteus medius contracts to maintain the pelvic tilt steady. (Jay Dicharry, 2010). The pelvis is posteriorly inclined at footstrike but retains a net anterior tilt of around 10°. The pelvis begins to anteriorly tilt when the stance phase begins. Up to 20° of anterior tilt occurs soon after toe-off. Tight muscles that attach to the pelvis, weaker muscles, or a structural deformity such as scoliosis or a leg length discrepancy can all create abnormal pelvic mechanics, which can alter running stride and lead to overuse injury.

KNEE KINEMATICS

The knee is in a valgus posture and flexes during pronation. It is in varus posture and expands during supination. During the stance and swing stages, it flexes twice. At footstrike, knee flexion ranges from 20° to 25° and continues to 45° at midstance. Flexion at the start of the stance phase acts as a shock absorber. Following foot striking, the quadriceps contract eccentrically to oppose knee flexion. The degree of pronation inside the foot tends to influence the degree of knee valgus as well, in that the more pronation there is, the more knee valgus there is during the stance phase. Depending on pace, the knee will flex to a maximum of 90° to 130° during the swing phase. During the swing phase, the muscles crossing the knee create very little power. The rectus femoris eccentrically contracts in the early swing to prevent over-flexion of the knee, while the hamstrings eccentrically contract in the late swing to prevent overextension. The major function of the quadriceps group is to extend the knee. The vastus lateralis, rectus femoris, vastus intermedius, and vastus medialis all work together to extend the knee at the superior pole of the patella. During swing, the rectus femoris also acts as a hip flexor. The quadriceps rest at full flexion and then tighten to commence knee extension during the late swing phase. The knee will extend to within 10° to 20° of full extension. This provides for maximal stride length and enhances propulsion by increasing the time spent in the air during the swing phase. Greater stride lengths increase ground reaction forces at impact, potentially interfering with synchronization between the knee and ankle joints and increasing the risk of injury.

ANKLE AND FOOT KINEMATICS

The talocrural or true ankle joint permits motions in the sagittal plane (plantar flexion and dorsiflexion) while the subtalar joint permits frontal plane motion of the foot (inversion and eversion). At foot contact, the position of the talocrural joint is approximately 5 degrees of plantar flexion to neutral, and then immediately moves to about 10 degrees of dorsiflexion as the heel is lowered to the ground (Loudon & Reiman, 2012). In the mid-stance phase the trunk and stance leg is moved anteriorly over the stationary foot placing the ankle joint in approximately 20 degrees of dorsiflexion. As the momentum carries the body forward, the heel is lifted off of the ground moving the ankle into plantar flexion. At take-off the ankle is in approximately 25 degrees of plantar flexion. During swing phase, the ankle moves from plantar flexion to dorsiflexion in the forward swing phase, and then back to plantar flexion at the end of foot descent and right before the next foot contact.

A runner who is a rearfoot striker will make initial foot contact with the ground in 6 to 8° of inversion, striking first with the heel (Nicola & Jewison, 2012). Immediately after heel strike until mid-support, the foot moves into eversion, unlocking the transverse tarsal joint allowing the foot to attenuate the ground reaction forces. The greatest amount of inversion (6 to 8°) occurs at approximately 40% of the entire stance phase. Then, at mid-support phase the subtalar joint moves into eversion, locking the tarsal joints and providing a rigid lever for take-off (Dugan & Bhat, 2005).

1.4 MUSCLE ACTIVATION PATTERN DURING RUNNING

Running can only be conducted smoothly should the muscles controlling the lower extremity movements be strong enough and timed efficiently. Muscles from the abdomen and back all the way down to the toe flexors and extensors work in unison specific sequence. When chaos occurs and timing is off, injury can occur.

Trunk and Pelvic Muscle Activation: The muscles of the abdomen, back, and hip girdle, along with the gluteal and diaphragm muscles work collectively to control breathing and perform the necessary trunk flexion and rotation motion required during running (Schache et al., 1999). When the pelvis rotates internally and externally with each stride, the muscles of the trunk keep the spine and abdomen stable. During the stance phase of running, the gluteus medius is responsible for maintaining a neutral and stable pelvis (Jay Dicharry, 2010). Posterior and anterior pelvic tilt is performed with contraction of the hamstrings and quadriceps respectively.

Hip Muscle Activation: At initial foot contact the hamstring muscles and the gluteus maximus are contracting eccentrically to limit hip flexion and stabilize the stance limb. The gluteus medius and tensor fasciae latae are attempting to limit the degree of hip adduction range of motion by counteracting the hip adductors that are working concentrically. As the limb moves into the mid-support phase, the gluteus medius and tensor fascia latae are acting eccentrically to maintain a level pelvis from which the swing leg moves. All the way through to take-off, the gluteus maximus and hamstrings are concentrically moving the limb into hip extension. Hip extension at take-off is primarily facilitated by the gluteus maximus (Schache et al., 1999). During the take-off phase, the gluteus medius is concentrically performing hip abduction. Overall, females have demonstrated greater peak and average gluteus maximus activation during running compared to males (Willson et al., 2012). No differences in gluteus medius activation between females and males has been established. During the beginning of swing phase, the hamstrings and gluteus maximus extend the hip to pull the body forward, while the hip flexors eccentrically contract to control excessive hip extension. Subsequently, the hip flexors, iliopsoas, rectus femoris and tensor fascia latae, become the primary force generators for forward swing driving the hip into flexion. Finally, during foot descent the gluteus maximus and hamstring muscles decelerate the thigh as it moves into flexion and the gluteus medius and tensor fascia latae prepare the pelvis for contact.

Knee Muscle Activation: The quadriceps femoris muscle group and the hamstring muscle group are active prior to initial foot strike to prepare the stance limb for ground contact. The hamstring muscles slow the rapidly extending knee, while the quadriceps muscles act as braking forces providing the primary means of shock absorption from initial contact to mid-support (Novacheck, 1998). From mid-support to take-off the quadriceps muscles then work eccentrically to resist knee flexion. Once the swing phase begins, the hamstrings concentrically move the knee into extension. As forward swing is initiated the quadriceps and hamstrings muscles co-contract, generating minimal power (Novacheck, 1998). During foot descent the hamstring muscles slow knee extension by contracting eccentrically.

Ankle and Foot Muscle Activation: The anterior tibialis muscle is activated instantly at initial foot contact in order to control the foot slap or downward momentum of the forefoot (Loudon & Reiman, 2012). However, control of the foot slap is only present in the rearfoot, and slightly in the midfoot striker, while it is absent in a forefoot striker. During initial-contact, the ankle plantar-flexors are eccentrically contracting to help absorb the impact. After initial contact and through mid-support the center of mass falls medial to the stance limb forcing the gastrocnemius and soleus to work eccentrically to stabilize the subtalar joint and limit excessive pronation. From mid-support to take-off the gastrocnemius is the primary generating of the anterior propulsive energy. Additionally, during take-off, the toe flexors and fibularis muscles are concentrically contracting to assist in the propulsion of the body, while the toe extensors are working to stabilize the toes for a stable take-off. During the swing phase the gastrocnemius initially concentrically contracts through follow-through. Then during forwarding swing, the ankle dorsiflexes to provide clearance of the foot over the ground. Lastly, during foot descent, the tibialis anterior maintain dorsiflexion to prepare the foot for its next contact with the ground.

2. CONTRALATERAL PELVIC DROP

The contralateral pelvic drops (CPD) mean a condition that the opposite hip to the weight-bearing leg is lower than the frontal-back plane with single leg weight-bearing (Souza & Powers, 2009). Increased contralateral pelvic drop has been associated with a number of different running-related injuries. It has been proposed that this changed kinematic pattern is the consequence of hip adductor muscle weakness, resulting in an inability to eccentrically regulate frontal plane motion of the pelvis during the early stance phase of running. Another explanation is that greater adductor activity destabilizes the pelvis in the frontal plane, increasing hip adduction and resulting in an increase in pelvic drop (Preece, Elsais, Jones, & Herrington, 2019).

The hip joint, as the primary linkage between the trunk and the lower limb, plays a important role in the creation and transfer of forces during both daily activities and sporting activity. This joint has an unusual level of intrinsic bony stability, with changes in osseous architecture having a substantial influence on the biomechanical qualities of the human hip. The physical stresses exerted on the hip joint during sporting activities may lead to injury or other chronic pathologic processes, and these biomechanical concepts have substantial implications for the diagnosis and surgical treatment of structural hip problems.

2.1 HIP ANATOMY AND MUSCLE

The hip joint is a ball-and-socket joint made up of the acetabulum and femoral head. The acetabulum concavity develops in response to the presence of a spherical femoral head. Muscles attached in this area also support the hip joint strength. At the middle of the top of the femur head locates a tendon called ligamentum teres holding from the femur head to the lower part of acetabulum. This ligament is quite flaccid while movement is manipulated. Besides, it is also found that ligamentum teres is a path for vessels that nurture the femur head. There are 3 planes and 3 axes of hip movement as follow.

1. Transverse Axis: It is a rotation point passing the hip joint from left to right. Sagittal plane is given with flexion-extension movement. Motion range is Flexion/Extension: $120^{\circ}/0^{\circ}/30^{\circ}$.

2. Vertical Axis: It is a rotation point passing the hip joint from the upper to lower part. Transverse plane is given with internal rotation and external rotation movement. Motion range is Internal/external rotation: $45^{\circ}/0^{\circ}/45^{\circ}$.

3. Sagittal Axis: It is a rotation point passing the hip joint from the front to back part. Frontal plane is given with abduction and adduction movement. Motion range is Abduction/adduction $45^{\circ}/0^{\circ}/30^{\circ}$.

According to Polkowski and Clohisy (2010), over 24 muscles engage on the hip joint to create six essential motions: flexion, extension, abduction, adduction, internal rotation, and external rotation. These muscles have several effects on the hip joint that vary according on joint position. Furthermore, in the case of muscles that span both the hip and the knee, the location of the knee influences the function of the hip muscles. The iliopsoas muscle complex, which includes the psoas major, psoas minor, and iliacus muscles, is the strongest hip flexor. The transverse processes of the 12th thoracic to the fifth lumbar vertebrae, the anterior surface of the iliac crest, and the anterior sacrum give rise to this muscle group. Distally, these three muscles join to produce a single tendinous insertion on the lesser trochanter. The rectus femoris and sartorius are two more hip flexors, however they are obviously secondary to the iliopsoas in terms of force production. Table 1 depicts hip position, muscle function, and percent incidence during the gait cycle at various stages of walking.

The gluteus maximus is the primary extensor of the hip. It is a strong and powerful muscle that inserts on the posterolateral iliotibial tract and the gluteal tuberosity. The biceps femoris, semimembranosus, and semitendinosus start in the ischial tuberosity and traverse the knee joint to insert on the posteromedial tibial plateau (semimembranosus and semitendinosus) and fibular head (biceps femoris). When the knee is extended, these three muscles also operate as hip extensors.

Table 1 hip position, muscle function, and % occurrence during the gait cycle during the various phases of walking.

Phase of Gait	Hip Position	Active Muscles	Occurrence During Cycle (%)
Stance			
Initial contact	30 degrees of flexion	Hamstrings and gluteus maximus	0-2
Loading response	30 degrees of flexion	Hamstrings and gluteus maximus	0-10
Mid-stance	5 to 10 degrees of adduction 5 to 10 degrees internal rotation 0 degrees of flexion-extension Neutral abduction-adduction	Gluteus medius, gluteus minimus, Gluteus medius, gluteus minimus,	10-30
Terminal stance	10 degrees of extension	Iliacus	30-50
Pre-swing Swing	0 degrees of flexion-extension	Iliacus and adductor longus	50-60
Swing			
Initial swing	20 degrees of flexion	iliopsoas, rectus femoris, gracilis, and sartorius	60-73
Mid-swing	5 degrees of abduction 20 to 30 degrees of flexion	iliopsoas, gracilis, and sartorius	73-87
Terminal swing	30 degrees of flexion	Hamstrings and gluteus maximus	87-100

Source: Hughes, Hsu, and Matava (2002)

The primary abductors of the hip are the gluteus medius and gluteus minimus, which start in the ilium's outer cortex and insert on the greater trochanter. Impairment in hip abductor function can cause a Trendelenburg gait pattern, which is characterized by a compensatory upper-body shift to the afflicted side in order to keep the center of gravity over the damaged hip joint and prevent pelvic descent. (Hughes et al., 2002)

The three primary hip adductors are the adductor longus, adductor brevis, and adductor magnus. These muscles arise from the inferior pubic rami, ischial tuberosity, and pubis, and have insertion sites on the adductor tubercle (adductor magnus) and the linea aspera on the medial part of the femur. Although there is no primary internal rotator of the hip, the tensor fascia latae, anterior section of the gluteus medius, and gluteus minimus work together to elicit internal hip rotation. External hip rotation is caused by a group of tiny muscles that start in the pelvis and insert mostly along the posterior half of the greater trochanter and proximal femur. The obturator internus, obturator externus, superior gemellus, inferior gemellus, piriformis, and quadratus femoris are among these muscles.

2.2 HIP BIOMECHANICS

HIP MOTION

Literature review described the biomechanics of the hip implications for athlete (Hughes et al., 2002; Polkowski & Clohisy, 2010). There is a substantial body of study on hip biomechanics in both static weightbearing settings (e.g., single and double-leg stance) and dynamic scenarios (e.g., walking and stair-climbing). Despite the importance of the hip joint in numerous sports endeavors, there has been little published about hip biomechanics in the athletic population.

Because of its anatomic congruity, the hip has remarkable stability and movement within six degrees of freedom. The sagittal plane has the most hip range of motion. The active hip flexion angle is 120° when the knee is flexed and 90° when the knee is completely extended. 4With the knee flexed; passive hip flexion is roughly 140°. Active hip extension ranges from 10° to 18°, whereas passive extension can reach 30. When the knee is flexed, tightness of the rectus femoris or the iliofemoral ligament might hinder hip extension. Normal hip abduction is at least 50 degrees, and adduction is at least 30 degrees (restricted by the opposite extremity and the tensor fascia latae). The capsuloligamentous structures, musculotendinous units, and hip bone architecture all contribute to the overall limiting of this motion. The placement of the knee joint severely limits hip flexion, with knee extension dramatically limiting hip flexion due to increased load on the hamstring muscle, which runs through both joints. The iliofemoral ligament, anterior capsule, and hip flexors all limit hip extension. With the hip joint flexed, internal rotation ranges from 0 to 70 degrees, whereas external rotation ranges from 0 to 90 degrees. Because the soft tissue components around the hip are under higher stress when the hip is extended, there is much less internal and external rotation.

The combined motion of the hip joint and pelvis contributes to total hip motion, and the ranges of motion indicated above include pelvic motion contributions. Dewberry et al described disparities in the amount of pelvic posterior rotation, with lumbopelvic rotation with the knees flexed accounting for 26% of hip flexion and lumbopelvic rotation with the knees extended accounting for 39% of hip flexion. Pelvic rotation has been shown to contribute roughly 18% of hip flexion during weight-bearing exercises. In extension, 20 tissue components around the hip are under increased stress, limiting the degree of rotation.

Finally, the degree of hip mobility in each plane is determined by the athlete's total flexibility. Certain activities, such as gymnastics, need a greater degree of hip flexibility than others, such as marathon running. As people age, their range of ambulatory hip mobility decreases gradually due to a commensurate decrease in stride length. Certain individuals of the athletic population have been shown to have limited hip range of motion. Some non-elite long-distance runners with less flexibility than their more flexible counterparts, for example, have been proven to have higher running efficiency. The increase in running economy in these athletes is assumed to be due to a relative lack of energy expenditure by the musculotendinous units around the hip during the act of running when compared to the more flexible runner. Similarly, hip extension was found to be 10 degrees lower in professional ice hockey players than in age matched controls, and some researchers believe hip flexion contractures are a possible source of chronic low back discomfort in some sportsmen (Polkowski & Clohisy, 2010).

HIP MOTION IN RUNNING GAIT

Running is defined as the absence of the double-stance phase during the gait cycle. A float phase, a time of non-support where both feet are off the ground, occurs at this stage and lasts around 30 percent of the gait cycle. Running also has a shorter overall length of weightbearing than walking, with the swing phase accounting for 70% of the running gait cycle and the stance phase accounting for the remaining 30%-35 percent. This is in contrast to the 40–60% swing–stance ratio observed during walking.(Hughes et al., 2002).

When the speed of running rises, several small modifications occur in the running gait cycle. The complete hip range of motion is increased first. Second, because of the increasing degree of knee flexion, the leg's center of gravity approaches the hip. As a result, despite the larger angular velocity and acceleration, less torque is required to propel the leg forward throughout the swing. Third, when gait velocity rises, the rectus femoris acts more as a hip flexor in the swing phase than as a knee extensor in the stance phase.

Electromyographic investigations have shown that when running, the swinging leg and arm action propels the body forward rather than the stance limb. During late swing, the hip flexors (iliopsoas and rectus femoris) and knee extensors (vastus intermedius, vastus medialis, and vastus lateralis) have the maximum amplitude of concentric contraction. Many of the biomechanical processes mentioned during running occur at the same time, resulting in a synchronized sequence of motions in both the upper and lower limbs. The body’s center of gravity reaches peak height during the float phase. There is also a slight forward lean throughout the running cycle, primarily because of increased hip flexion. There is a reversal of hip flexion, fast knee extension, and dorsiflexion of the ankle before to initial contact. These occurrences prime the body for impact during the final float period. When there is a collision, there is a ground response force of around 150 to 200 percent of body weight, a forward shear force of 50 percent of body weight, and a medial shear force of 10 percent of body weight. These stresses are spread across the lower extremity's joints. This phenomenon is required to maintain joint stability across the lower extremities. As the speed of the run rises, so does the degree of eccentric muscle contraction around the hip.

At all gait speeds, the hip abductors have the same time of activation. They become activated in the late swing and stay active for half of the stance period. The hip abductors have a peak output of around 1 watt/kg. (Sadeghi, Allard, & Duhaime, 2000). To prevent excessive drooping of the swing leg hemipelvis, the hip abductors operate to support the stance leg hemipelvis at the point of initial contact. To stabilize the hip when there is forward motion, the adductor magnus, gluteus maximus, and tensor fascia latae are all activated during the loading response of the stance phase. As the lower extremities bears the weight of the body, the muscles around the hip and knee contract to support these joints. There is a fast extension of the hip, flexion of the knee, and dorsiflexion of the ankle during heel strike. Internal rotation of the whole leg causes calcaneal eversion and, as a result, the transverse tarsal joints to unlock. As a result, the foot is more flexible, which helps absorb energy upon impact.

Adduction of the hip also occurs when of impact. The pelvis begins to externally rotate after the swinging leg has passed the stance leg and the center of gravity is in front of the stance leg, which is begun by the swinging leg. The calcaneus is inverted as a result of the external pelvic rotation, and the transverse tarsal joint and long arch of the foot are stabilized. Before the beginnings of knee extension and ankle plantar flexion, which signal the start of push-off, this hindfoot stability lasts for half of the stance phase.

The long head of the biceps acts to initiate hip extension in the stance phase of running as the center of gravity moves in front of the knee. There is also progressive abduction of the hip as the joint extends. Progressive hip extension during the stance phase is accomplished through the synergistic function of both the hamstrings and gluteus maximus muscles. The rectus femoris, iliopsoas, tensor fascia latae, and adductor magnus are all active to control hip extension and prepare the hip for flexion. The action of these muscles during the loading phase also helps with hip joint stability in both the sagittal and coronal planes.

The hamstrings have longer periods of activity in the swing and stance phases of jogging and running, compared with walking. The hamstrings are active for the last 50% of the swing phase in jogging and for the last 25% of the swing phase in running. They are active during the initial 50% of the stance phase of both jogging and running, and they function synergistically with the gluteus maximus to bring about rapid hip joint extension during running. The short head of the biceps acts primarily to control the knee and has little or no function at the hip (Hughes et al., 2002)

Throughout the swing phase of the running cycle, concentric and eccentric contractions of the various muscles that regulate the hip occur simultaneously. The iliopsoas and rectus femoris, as hip flexors, are most active in the middle of the swing. Hip flexion and pelvic stability are also assisted by the tensor fascia lata and adductor magnus. The semimembranosus and long head of the biceps contract eccentrically to control hip flexion. This function is assisted by the gluteus maximus, but only while running at a fast rate. The semimembranosus, long head of the biceps, and gluteus maximus all initiate hip extension eccentrically in late swing to restrict hip flexion (with assistance from the adductor magnus, which can extend the hip from a flexed position). The semimembranosus and long head of the biceps function predominantly on the hip, while the short head of the biceps does not aid in knee flexion. During the swing phase, the rectus femoris eccentrically regulates knee flexion while concentrically flexing the hip.

Starting of the float phase, there is rapid hip flexion by the iliopsoas and rectus femoris and corresponding passive knee flexion and ankle dorsiflexion. In mid-float, hip flexion is at its peak and active knee extension begins. Rapid adduction of the hip occurs during the last half of swing. At terminal swing, there is a rapid reversal of hip flexion, the initiation of hip extension, and knee extension. During the last 25% of swing, the hip extensors, hamstrings, quadriceps, and ankle plantar flexors are all active to prepare for initial ground contact 90 (Hughes et al., 2002)

2.3 FORCES ACTING ON THE HIP

In the biomechanical and orthopedic literature, calculations of the forces that occur at the hip joint are widespread, with the most typical diagrams and explanations being the free body diagram showing the forces across the hip joint that occur during single limb stance (Polkowski & Clohisy, 2010).

Under static conditions the following forces are seen to act on the pelvis and hip joint to keep the pelvis level (Figure 2): gravitational force, W, which is the weight of the body minus the weight of the contralateral lower limb; A, which is the force of the abductor muscles acting to keep the pelvis level; and F, which is the force exerted by the femoral head on the acetabulum, or the joint reaction force. It is possible to determine the hip joint reaction force, F, once the abductor force is calculated. With knowledge of the individual's weight, moment arm of the gravitational force, d, and moment arm of the abductor musculature, l, the abductor force, A, can be calculated according to the following equation:

In equilibrium, the sum of the force vectors, A, F, and W equal zero, thus with the addition of vectors A and W, the magnitude and direction of the joint reaction force, F, is calculated to be 2.7 times the body weight with a direction of 69 degrees from the horizontal during single leg stance with the pelvis being kept parallel to the floor.

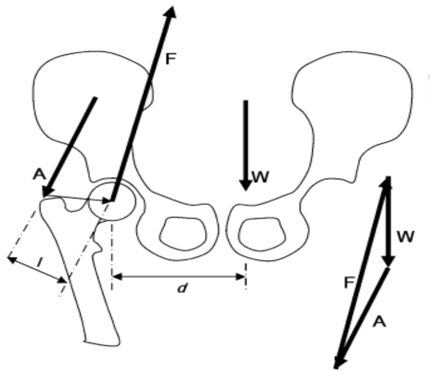


Figure 2 Forces acting on the hip joint during single leg stance under conditions of equilibrium. Gravitational force W, abductor muscle force A, hip joint reaction force F, abductor muscle moment arm l, and force of gravity moment arm d.

Source: Polkowski and Clohisy (2010).

A Trendelenburg gait is observed when a person lateral flexion in the coronal plane during the stance phase, such that a greater proportion of his weight is centered over the standing leg. The basic hip biomechanics helps explain why this type of stride is beneficial in the case of a sore hip. The moment arm of the gravitational force is lowered when the individual's weight is transferred over the standing leg and closer to the hip center of rotation, reducing the force that must be generated by the abductor muscle to oppose the pull of gravity on the pelvis. As a result, the force/load created at the hip joint is reduced overall, with the reduction corresponding to the reduction in the moment arm of the gravitational force. To put it another way, the worse the Trendelenburg "tilt," the lower the strain over the hip joint.

Because variations in the amount of the force of gravity's moment arm are linked to the Trendelenburg gait pattern, they can be manipulated using a cane to assist lower the load over the hip joint. When walking with a cane in the contralateral hand, an upward directed force is generated, which helps offset the force of gravity on the patient's weight, resulting in a reduction in the amount of abductor force required to keep the pelvis level, and a corresponding reduction in load across the hip joint. The amount of cane ground reaction force necessary to affect a reduction in contralateral hip joint reaction force is proportionally much less because the moment arm of the cane’s force is considerably longer than the moment arm of the contralateral abductor musculature. This reduction in force may be estimated, and some experts estimate it to be around 20%. Others have discovered that using a cane to maximize effort can result in a 42 percent reduction in muscular activity, which coincides with a drop in hip joint response force from 3.4 to 2.2 times body weight. During running, forces equivalent to 7 to 8 times body weight are transmitted across the hip joint during heel strike and increase to a value slightly higher than that during toe-off. It should be noted that these calculations are based on an individual moving forward in a straight line, and these do not take into consideration activities that are seen in athletes of other sports such as basketball, tennis, and football, which require a great deal of cutting, twisting, and pivoting (Polkowski & Clohisy, 2010).

According to Takacs and Hunt (2012) stated that the pelvic motion is dependent on the interaction of the lower limbs. The center of mass shifts to the non-stance limb, increasing the hip and knee lever arm and, as a result, the hip and adduction moments. Pelvic drop caused by hip abductor weakness has been proposed as a possible moderator of frontal plane knee joint kinematics during locomotion in people with knee osteoarthritis. (Chang et al., 2015). However, hip muscle strengthening training have poored to improved reductions in frontal plane loading measures such as the external knee adduction moment (KAM) with altered hip strength.

2.4 CONTRIBUTED FACTORS OF CONTRALATERAL PELVICD DROP

2.4.1 Weakness of hip muscle: according to Mansfield and Neumann (2019), the primary hip abductor muscles include the gluteus medius, gluteus minimus, and tensor fasciae latae, the piriformis, sartorius, and superior fibers of the gluteus maximus are considered secondary hip abductors. When the pelvis is stabilized, the hip abductor muscles contract, pulling the femur away from the midline. This motion usually puts these muscles under minimal stress. Closed-chain exercises, such as standing on one leg with the femur fastened to the ground, are a more demanding (and common) activity for these muscles (so-called single-limb support). Prove to yourself that "lifting" the left side of your pelvis with only your right leg requires a rather significant contraction of your right hip abductors (These muscles can be palpated midway between the greater trochanter and the iliac crest). Similarly, if you progressively descend the left side of your pelvis, eccentric activation of the right hip abductor muscles occurs. The axis of rotation for any pelvic motion lies through the middle of the femoral head and runs anterior-posterior. Walking places the highest strain on the hip abductors. Consider the demands on the right abductor muscles during the single-limb support phase of walking while the left limb swings forward. To keep the pelvis from "dropping into the gap" formed by the advancing left leg, the right hip abductors must provide enough contraction power. Weakness of these muscles results in an unstable pelvis while walking or while attempting to stand on one leg. Moreover, Hip abductor strength was poorly correlated to the magnitude of pelvic drop during the static Trendelenburg test and during walking in control group and nonspecific low back pain. The results suggest that hip abductor strength may not be the main factor to improve pelvic stability, and the static Trendelenburg test has limited use as a measure of hip abductor function (Kendall, Schmidt, & Ferber, 2010)

However, Preece et al. (2019) explored the association between adductor muscle activation during early stance and pelvic drop. This is a first study to investigate the link between the activation of the adductor muscles and pelvic drop during running. The findings do not support the idea that hip abductor weakness underlies pelvic drop. Instead, we suggest that pelvic drop may result from an altered synergy of the hip extensor muscles during the early phase. Specifically, increased activity of adductor magnus (a hip extensor) and decreased activity of the hamstrings and gluteus maximus destabilize the pelvis in the frontal plane but still provide appropriate sagittal plane moments. Further research on participants with running injuries is required. However, this funding may suggest that is required away from muscle strengthening towards clinical techniques which can bring about changes in muscle coordination patterns.

2.4.2 Q-Angle: Peak pelvic drop during the unilateral partial squat exercise had no significant relationship with Q angle or hip extension strength. Peak pelvic drop appears to be more closely linked to biomechanical limb posture, hip ABD strength, and subject demographics. The predictive ability of this dynamic assessment tool based on kinematic data across many joints is demonstrated by the regression model ran on the repeated unilateral partial squat. The findings might assist clinicians check for excessive pelvic drop in female athletes and offer suggestions for remedial conditioning based on the prediction model to help avoid knee damage and guide return to sport following lower extremity surgery (Nguyen, Boling, Levine, & Shultz, 2009).

2.4.3 Sex-biomechanics: The literature has documented biomechanical variations in male and female running kinematics. Females have much more knee abduction during the stance phase of running than males, according to several authors. During stance, female runners had more peak hip internal rotation and adduction. (Ferber, Davis, & Williams, 2003). The lack of strength in the proximal hip stabilizers may contribute to these gender differences during performance. Zeller, McCrory, Ben Kibler, and Uhl (2003) studied kinematic and EMG of male and female completing a single leg squat, reported that the mean maximum EMG activation for the gluteus medius was 77.3% of maximum voluntary contraction for males and 41.0% for female and the subjects also demonstrated greater knee abduction during this closed chain activity and suggested that this kinematic difference in performance of a single leg squat may be related to gender differences in muscle activation patterns of the hip. Presently, the relationship between proximal hip strength and knee alignment has been largely speculative. Because vertical ground reaction forces in running are the greatest at approximately 45 to 50% of stance, it can be postulated that weakness in the gluteus medius may result in greater knee abduction during mid - stance of running as the hip attempts to maintain dynamic control of the limb.

2.4.4 Peripheral motor impairment: Peripheral motor impairment is caused by arthritic, myopathic, and neuropathic disorders that cause extremity deformities, uncomfortable weight-bearing, and localized weakness. The compensatory gait abnormalities that ensue are the most common. Trendelenburg gait (weight shift over the weak hip due to hip abductor weakness); antalgic gait (avoidance of excessive weight-bearing and shortening of stance on one side due to pain); and "steppage" gait (excessive hip flexion to facilitate foot clearance of the ground, seen in patients with foot drop due to ankle dorsi flexion).

2.4.5 Neuromuscular system: According to Ford et al. (2015), altered neuromuscular control methods during landing in woman athletes might be a contributing cause to lower extremities and ACL injuries. Males showed higher hip flexion at initial contact and larger hip extensor moment than females in a study of 315 young athletes. Females also showed a substantial preference for underusing the hip extensors over the knee extensors, indicating a sex-specific hip strategy during drop vertical leaps. Decker, Torry, Wyland, Sterett, and Steadman (2003) showed a decrease in negative joint work (decreased eccentric muscle contraction to absorb landing forces) at the hip in females compared with males during landing. Similarly, ACL reconstruction patients showed higher hip moments during the stance phase of walking, suggesting that the ACL is better protected. In comparison to controls, patients with patellar tendinopathy had higher hip joint moments during hopping. 34 Neuromuscular control techniques for managing and correcting for knee loads during a variety of complicated motions may rely heavily on proximal processes. Hip kinematics and kinetics are improved through neuromuscular training.

Lephart et al. (2005) found increased hip flexion at initial contact and increased peak internal hip extensor moment following a plyometric training protocol. These authors suggested that the modifications at the hip likely increase the hamstring forces that protect the ACL. Hip posture may play an important role in the mechanical efficiency of hamstrings in relation to quadriceps (Shultz, Nguyen, & Levine, 2009). Clearly, the hip plays a primary role in dynamic lower extremity valgus. Moreover, Pelvis drop can occur even in healthy individuals with normal abductor mechanism when the abductor muscle is not working adequately (Lewis, Laudicina, Khuu, & Loverro, 2017).

3. RUNNING ECONOMY

Running economy is typically defined as the energy demand for a given velocity of submaximal running and is determined by measuring the steady-state consumption of oxygen (VO_2) and the respiratory exchange ratio (Saunders et al., 2004). Taking body mass (BM) into consideration, runners with good RE use less energy and therefore less oxygen than runners with poor RE at the same velocity. There is a strong association between RE and distance running performance, with RE being a better predictor of performance than maximal oxygen uptake (VO_2max) in elite runners who have a similar VO_2max. RE is traditionally measured by running on a treadmill in standard laboratory conditions, and, although this is not the same as over-ground running, it gives a good indication of how economical a runner is and how RE changes over time.

Many physiological and biomechanical factors appear to influence RE in highly trained or elite runners. These include metabolic modifications within the muscle, such as enlarged mitochondria and oxidative enzymes, higher muscular stiffness, and more effective mechanics, which result in less energy squandered on braking forces and excessive vertical oscillation.

Athletes, coaches, and sport scientists are always looking for ways to enhance their RE. Strength training and altitude training are two strategies that have recently attracted a lot of attention. Strength training permits muscles to use more elastic energy while reducing energy lost in braking forces. Altitude exposure improves some metabolic characteristics of skeletal muscle, allowing for more efficient oxygen consumption. The improving athletes RE is related to improvements in distance running performance. RE is likely to be influence d by several factors (Figure 5) and any intervention (training, altitude, heat) that can reduce the oxygen cost over a range of running velocities will conceivably lead to enhanced performance.

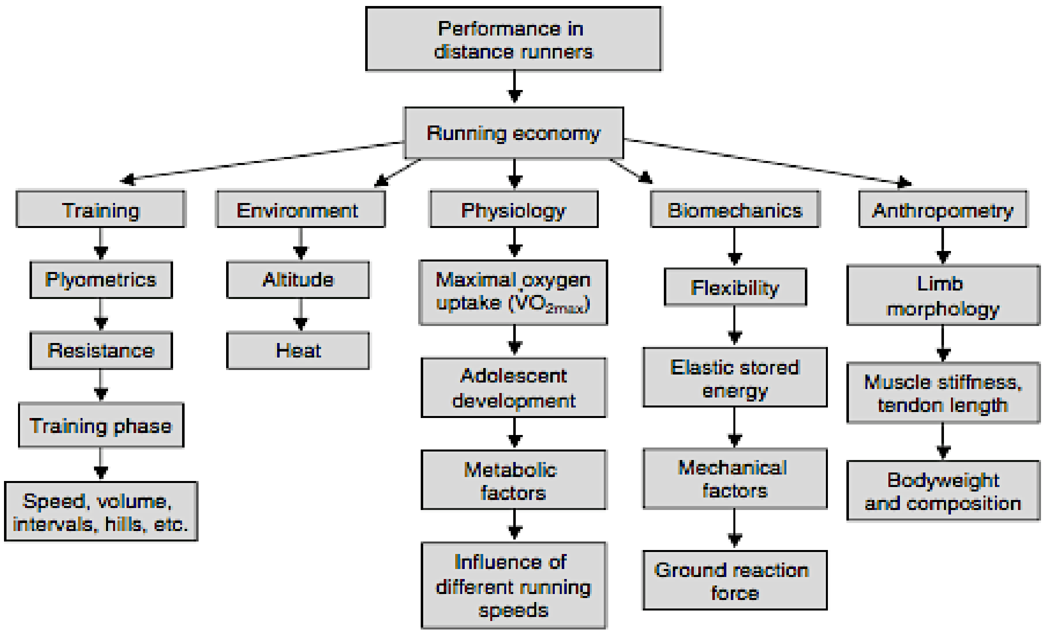


Figure 3 Factors affecting running economy.

Source: Saunders et al. (2004)

3.1 BIOMECHANICAL FACTORS AFFECTING RUNNING ECONOMY

According to Anderson (1996), running requires the conversion of muscular forces through complicated movement patterns involving all of the body's main muscle joints. Running at a high level requires expertise and exact timing, with each movement serving a specific purpose. Changing components of running mechanics that cause a runner to expend less energy at any given pace is clearly beneficial to performance.

The spring-mass model is an important factor related with RE, where the bounce of the body on the ground is counteracted by the spring behavior of the support leg. Mechanical energy is stored in the muscles, tendons, and ligaments that operate across joints during the eccentric phase of contact. Recovery of stored elastic energy during the concentric phase minimizes energy expenditure. A resonant frequency is another characteristic of an oscillating system. After a mechanical stimulus, the resonance frequency is the frequency at which a system freely vibrates. The propulsive leg's muscular stiffness ($r = 0.80$) and resonant frequency ($r = 0.79$) were shown to be strongly associated, with stiffer muscles functioning at lower resonant frequencies eliciting the best RE (Dalleau, Belli, Bourdin, & Lacour, 1998).

Runners can be more or less economical depending on velocity, with both physiological and biomechanical factors contributing to RE. Williams and Cavanagh (1986) reported that 54% of RE variation can be explained by biomechanical factors. Specifically, the timing and motion of a runner’s stride, ground reaction force application, and optimization of elastic energy return can influence RE

3.1.1 Anthropometry: Anthropometric variables such as height, limb proportions, body fat, and body mass index (BM) have all been investigated as possible implications on RE. While leg length affects angular inertia and the metabolic expenditure of moving the legs during running, there isn't much agreement on whether leg length is a significant component in determining RE.. Williams and Cavanagh (1986) reported a modest inverse relationship between BM and sub- maximal VO_2/kg ($r = -0.52$) and between maximal thigh circumference and submaximal $\dot{V}O_2$/kg ($r = –0.58$), indicating that heavier than average runners use less oxygen per kilogram of BM. Myers

(2005) studied that a runner with a proportionally smaller amount of BM localized in the extremities, particularly the legs, would expand less work moving their body segments during running, assuming that all other factors are unchanged (e.g. speed, BM, running style).

3.1.2. Kinematics: The study compared biomechanics factors between elite and good runners demonstrated less vertical oscillation, were more symmetrical, and had superior RE than average runners. Williams and Cavanagh (1986) found better RE was linked to a more stretched lower leg during foot strike, a lower vertical force peak, and a longer contact duration in elite male distance runners. As assessed by wrist excursion during the stride, more economical runners have less arm movement. In top male distance runners, greater maximum plantar flexion velocity and greater horizontal heel velocity at foot contact are also linked to improved RE (Williams & Cavanagh, 1986). While these authors found relationships between several kinematic characteristics and RE, it appears that further research is needed to see if modifying a runner's kinematics causes an increase in RE.

Sagittal plane kinematic parameters, such as flexion and extension of joints during running, affect RE (Williams & Cavanagh, 1986). For instance, reduced peak hip flexion during braking (Sinclair, Greenhalgh, Edmundson, Brooks, & Hobbs, 2012), greater knee flexion during stance phase, greater maximal thigh extension angle with the vertical, larger amplitude of the knee angle at foot strike, and less plantar flexion at toe off (Williams & Cavanagh, 1986) have been correlated to improve RE. Further findings included significant relationships between other kinematic parameters and RE in long-distance runners. Indeed, kinematic aspects such as reduced center of mass (Rizzolatti & Craighero, 2004) vertical excursion (Nummela, Keränen, & Mikkelsson, 2007), self-chosen stride frequency/length (Moore, 2016), as well as reduced plantar-flexion at high velocity during the terminal stance (William et al., 1985), have been linked to a lower energy cost of running. Although significant differences and trends in some kinematic parameters have been observed between economical (lower RE values) and less economical (higher RE values) runners, studies have shown contradictory results (Nummela et al., 2007).

Coronal plane of foot strike, the hip adducts relative to the pelvis due to a shock absorbing mechanism for the beginning of the stance phase (Ferber & Macdonald, 2014). During the remaining part of the stance phase, the pelvis drops until the start of double float, the moment in which it achieves the most oblique point. As the limb begins the swing phase, this motion reverses (Novacheck, 1998). Generally, in running the hip is adducted while the limb is loaded in the stance phase and abducted during the swing phase. This nearly reciprocal motion combined with slight lumbo-pelvic motion minimizes shoulder and head movement (Novacheck, 1998). During running, the analysis of the transverse plane shows that maximum internal pelvic rotation occurs in mid-swing to lengthen the stride, but at the time of IC, the hip is rotated externally. This maximizes horizontal propulsion force and avoids the potential loss of speed (Novacheck, 1998). Moreover, the hip has the function to be a pivot between the counter-rotating shoulders and legs. External rotation, which begins at around 20% of stance, makes up the majority of the entire transverse plane of motion. The hip abducts in a way similar to the knee during the second half of stance, but with a higher overall amplitude (Ferber & Macdonald, 2014). As a result, the hip and knee joints' timing is also asynchronous. Several publications have also documented this condition and the out-of-phase relationship between hip internal rotation and tibia internal rotation during the stance phase of gait.

3.1.3 **Kinetics:** Recent research has comprehensively investigated biomechanical factors affecting RE (Kyröläinen, Belli, & Komi, 2001). VO2 was compared to kinematic data and three-dimensional ground reaction forces (GRF) while telemetric EMG recordings of selected leg muscles were made at 12–13 various running speeds. Two-dimensional video analysis was used to determine joint moments and power, and the digitized segment coordinates were transmitted to a computer system. The biomechanical characteristics studied (angular displacements between the ankle, knee, and hip joints; joint angular velocities) were ineffective in predicting RE. However, force output upon ground contact, as well as leg extensor activation during the pre-activity and braking phases, and their combination with longer-lasting hamstring activation, were important. Co-activation of muscles surrounding the knee and ankle joints enhances joint stiffness, which appears to be linked to improved RE, according to the scientists (Kyröläinen et al., 2001).

To better use the storage and release of elastic energy, mechanical aspects such as stride length and frequency, as well as the integration and timing of muscle activity, may be improved (Anderson, 1996). The idea that more efficient runners have distinct kinetic patterns in their running mechanics was supported by Williams and Cavanagh (1986). Ground-support time and peak medial force were shown to be associated to submaximal VO2 ($r = 0.49$ and 0.50, respectively). Lower initial peaks in the vertical component of the GRF, smaller antero-posterior and vertical peak forces, and a more dominating rear-foot striking pattern were all seen in more economical runners (Williams & Cavanagh, 1987). These features, according to the authors, influence muscle demands both before and during support, with forefoot strikers depending on musculature for cushioning, making them less cost-effective. During running, the muscles' primary function is to adjust the stiffness of the springs in order to optimize the use of elastic. While the required to sustain body mass has been found to alter metabolic demand during running in recreational and moderately trained runners, horizontal forces can also have a significant impact on RE. For example, at five different running speeds, mass-specific horizontal forces were significantly associated to RE in 25 well-trained endurance runners (Nummela et al., 2007))

3.2 NEUROMUSCULAR CHARACTERISTICS AND RUNNING ECONOMY

In addition to metabolic, cardiorespiratory, and biomechanical characteristics, neuromuscular variables are important components of RE. The neuromuscular system connects the neurological and muscle systems (i.e., the neuromuscular system) and successfully translates cardio-respiratory capacity into efficient mechanics and hence performance. It's apparent that aerobic factors aren't the only ones that affect endurance performance (Bonacci, Chapman, Blanch, & Vicenzino, 2009). Essentially, there are two types of variables that enhance neuromuscular efficiency: 1) those that improve brain signaling and motor programming of the running action, and 2) those that improve muscle force generation itself (Barnes & Kilding, 2015).

1. Neural signaling and motor programing

Like striking a golf ball or shooting a basketball, high-performance running necessitates exact synchronization of virtually all of the body's major muscles and joints to convert muscular power into translocation (Anderson, 1996). Practice, like other abilities, is required to enhance efficiency at the activity. Continued repetition of a task results in more proficient control of movement, defined by lower amplitude and duration of muscle activity, decreased muscle co-activation, and less variability of movement, according to motor learning research. (Burdet, Osu, Franklin, Milner, & Kawato, 2001). Recent evidence has shown that recreational runners (3.4 ± 2.8 km·wk^{-1}) exhibited greater individual variance (i.e. variability between strides), greater population variance (i.e. variability of muscle recruitment between athletes), more extensive and more variable muscle co-activation and longer durations of muscle activity than moderately trained runners (6.6 ± 1.4 years of running experience, who ran 61.4 ± 8.8 km·wk^{-1}) (Chapman et al., 2009). Previous short-term training studies of arm, hand, and leg (pedaling) movements have found similar results. (Burdet et al., 2001; Chapman et al., 2009), suggesting that prolonged training results in persistent neuromuscular adaptations. Run training has been shown in the literature to cause favorable improvements in RE. Running appears to cause motor programing and recruitment modifications that are necessary for improved RE. If neuromuscular adaptations are to responsible for the changes in RE, it's reasonable to expect changes in neural signaling during running after training.

Bonacci et al. (2009) propose for motor recruitment modifications as a learning effect because of training. Positive adaptations imply that an individual learns to create certain muscle activation patterns that are linked to increased task efficiency (e.g., higher biomechanical and neuromuscular efficiency), resulting in improved performance.

2. Muscle force production and stiffness

The speed of contraction and the balance between concentric and eccentric contractions are two muscular contraction-related concerns that might impact energy demand and RE. In terms of contraction velocity, it is less expensive for muscles to create force at low speeds, force is maximum and metabolic rate is lowest during isometric contraction, and the energy cost of creating force increases rapidly with increasing shorting velocity. (Taylor, 1994). Muscle contractions are primarily isometric, with the stiffness of the muscle-tendon unit being adjusted during the eccentric phase to produce simultaneous deceleration and elastic stretch, followed by a nearly isometric impulse that initiates ballistic concentric acceleration, according to the proposed mechanism. By using 'free' elastic energy and reducing metabolic needs, this suggested approach would encourage optimization. Such optimization would clearly need exact timing, as well as the integration and refining of temporal, kinetic, and kinematic patterns, which would necessitate a lot of practice and training.

3. Lower-leg stiffness

Shorter stance phase contact periods and higher muscular pre-activation might indicate increased leg muscle stiffness, resulting in a speedier transition from the braking to the propelling phase of ground contact. (Nummela et al., 2007). Dalleau et al. (1998) highlighted the importance of neuromuscular factors by demonstrating that RE was related to the stiffness of the propulsive leg, with greater stiffness eliciting the best RE (Arampatzis et al., 2006) corroborate this finding such that in a group of 28 long-distance runners separated into three groups by economy, the most economical runners had highest tendon stiffness. Neuromuscular activation regulates leg stiffness, and variations in stiffness have been seen as a result of neuromuscular adaptation to training. A reduction in EMG pre-activation was demonstrated to be strongly associated to a decrease in post-landing leg stiffness during fatiguing exercise, supporting the link between motor recruitment and leg stiffness. A longer length of muscular co-activation of bi-articular leg muscles during stance has also been linked to improved RE (Heise, Shinohara, & Binks, 2008). Muscle co-activation alters RE by using stored elastic energy at no additional metabolic expenditure.

4. NEUROMUSCULAR TRAINING

Neuromuscular training is the training program used to change movement patterns with exercises that are congruent with needed motions is known as neuromuscular training. Adopts motor learning principles by learning from errors or skills that need to be rectified and changing those specific abilities by relearning how to employ linked muscles to attain optimal biomechanical efficiency (Bonacci et al., 2009). Neuromuscular training aims to enhance the nervous system's capacity to create a quick and optimum muscle firing pattern, as well as promote dynamic joint stability, reduce joint forces, and recall movement patterns and abilities. The importance of neuromuscular training with neural mobilization on the motor nerve as a result of the learning process. Individual learning to produce a certain movement pattern is referred to as positive adjustment, and neuromuscular training leads to self-adjustment.

Bonacci et al (2009) claimed that the interplay between the brain and muscle systems (i.e. neuromuscular system) is crucial to all movement and efficiently converts cardiorespiratory capacity into efficient movement and hence performance. The neuromuscular system, like the cardiorespiratory system, has the potential to respond to training. Continuous practice of a task (i.e. training) allows neuromuscular adaptations, which are characterized by more skillful regulation of movement and muscle activation patterns, according to studies conducted over the last two decades. Changes in muscle electromyography (EMG) function reflect learning within the CNS and can be reflected by training-induced adaptations of descending motor signals (i.e. motor recruitment). motor activation The neuromuscular adaptations that occur with various modalities of training (e.g., running, cycling, multidiscipline training, strength training) and how these changes in neuromuscular control are linked to running economy are less well recognized. Neuromuscular adaptations were recently proposed as the cause of increases in running economy following strength and resistance training.

The adaptations in motor recruitment as a result of training represent a learning effect. Positive adaptations imply that a person learns to develop certain muscle activation patterns that are related with optimal task performance. This is distinct from the changes in neuromuscular function that occur because of exhaustion after prolonged exercise. Tiredness is a complicated phenomenon in and of itself, and considerable research has previously been done to better understand the processes of fatigue and output control during endurance exercise.

Adaptations of Muscle Recruitment to Single-Discipline Endurance Training

Continuous practice of a task results in more skilled control of movement, as measured by decreased amplitude and duration of muscle activity(Burdet et al., 2001; Osu et al., 2002), decreased muscle co-activation (Osu et al., 2002) and less variability of movement (Osu et al., 2002). These investigations, on the other hand, focused on innovative hand and arm movements over a short period of time (e.g., 1–2 days). Individual variation (variability across strides) and population variance were both higher among rookie runners. These findings are similar with earlier short-term arm and hand movement training studies (Osu et al., 2002), suggesting that continuing training results in ongoing neuromuscular adaptations.

Neuromuscular Characteristics and Running Economy

The authors hypothesized that, in addition to aerobic power and running economy, the neuromuscular system's capacity to create fast force repeatedly during maximum and submaximal running influences distance running performance in highly trained athletes. Shorter stance phase contact periods and more muscular pre-activation have been considered as indicators of increased leg muscle stiffness, resulting in a speedier transition from the braking to propulsive phase of ground contact (Nummela et al., 2007).

Dalleau et al. (1998), the relevance of neuromuscular variables was demonstrated by proving that running economy was related to propulsive leg stiffness, with greater stiffness evoking the optimum running economy. Neuromuscular activation regulates leg stiffness, and variations in stiffness have been seen as a result of neuromuscular adaptation to training (i.e., learning of more efficient or more skilled patterns of motor recruitment). A longer period of muscular co-activation of bi-articular leg muscles during stance has also been linked to improved running economy. Muscle co-activation reduces leg stiffness when running and may improve running economy by using stored elastic energy at no extra metabolic expenditure.

The stretch shortening cycle relies heavily on preparatory muscle activity (SSC). A SSC consists of a high-velocity eccentric muscle contraction followed by a concentric muscle contraction. The increase in anticipatory muscle activity with increased running speeds has been postulated to be a mechanism to withstand larger impact loads, regulate landing stiffness, and improve running economy. (Kyröläinen et al., 2001).

These data show that neuromuscular factors may play a significant impact in running economy, particularly in athletes with identical physiological parameters. The most consistent relationship between running economy and muscle activity timing and amplitude has been found. Increased leg stiffness and utilization of stored elastic energy may improve running economy by boosting muscular activity before to and during the initial phase of ground contact. Increased motor unit recruitment and synchronization are two of these adaptations. Resistance training improves running economy by improving leg muscle coordination and co-activation and lowering stance phase contact periods, allowing for a faster transition from the braking to the propelling phase via elastic recoil (Kyröläinen et al., 2001). Transfer occurs when training for one activity has an effect on the performance or learning of a subsequent one. In general, a positive transfer would mean that a certain pattern of muscle activation linked with great execution of a weight training activity increases running economy when demonstrated during running.

4.1 NEUROMUSCULAR TRAINING ALTERS MOVEMENT BIOMECHANICS

The neuromuscular training strategy that is based on biomechanical and neuromuscular principles and focuses to improve sensorimotor control and achieve compensatory functional stability. Neuromuscular exercise, as opposed to typical strength training, focuses on movement quality and joint control in all three biomechanical/movement planes. Functional performance, biomechanics, and muscle activation patterns in the joint musculature are all affected by neuromuscular exercise. Because the coordinated neuromuscular regulatory mechanism required for everyday life and sport-specific activities is disregarded, simply restoring mechanical restrictions is insufficient for joint functional recovery.(Ageberg & Roos, 2015)

Sensorimotor control or neuromuscular control is the ability to produce controlled movement through coordinated muscle activity. Functional stability or dynamic stability is the ability of the joint to remain stable during physical activity. According to Judd, Winters, Stevens-Lapsley, and Christiansen (2015), Neuromuscular reeducation techniques offer a strategy to improve movement quality by emphasizing hip abductor performance and pelvic stability. NMR techniques can be used to target the hip abductor muscles ability to stabilize the pelvis by resisting external moments during functional tasks. NMR techniques have successfully improved strength and postural stability, gait kinematics, and movement patterns, while also reducing the risk of injury in other populations such as patients with ankle injury and anterior cruciate ligament reconstruction.

According to Risberg et al. (2001) neuromuscular training programs are increasingly integrated into clinical practice for lower extremity rehabilitation. The objective of the neuromuscular training was to develop the ability to generate a quick and optimal muscle firing pattern, to increase dynamic joint stability, and to remember movement patterns and skills required during everyday living activities and sports activities. Neuromuscular train. Neuromuscular training is being used in therapeutic settings for both upper and lower extremity rehabilitation. Neuromuscular training, according to the notion of neuromuscular control, might be characterized as training that improves unconscious motor responses by activating both afferent signals and cerebral processes responsible for dynamic joint control. Movement compensations happened on knee and hip biomechanics, although neuromuscular training may improve regulation of aberrant joint translation during functional activities by causing compensatory changes in muscle activity patterns.

The movement compensations require targeted exercise to improve the ability of the body to produce stable, coordinated movements during functional tasks. Such exercise is clinically referred to as neuromuscular reeducation (NMR) (Ageberg & Roos, 2015). At the hip and pelvis, stability is largely dependent on the hip abductor muscles' ability to produce internal hip abduction moments to control pelvic motion during unilateral stance (Hardcastle and Nade, 1985). Optimal neuromuscular reeducation (NMR) targets movement compensations by promoting coordinated hip and pelvic muscle activity and pelvic stability (Willson, Dougherty, Ireland, & Davis, 2005), which requires integrating strength training with focused movement reeducation feedback techniques, rather than isolated strength training (Willy & Davis, 2011).

Neuromuscular reeducation (NMR) and single limb support during running

NMR approaches can be utilized to target the hip abductor muscles' ability to stabilize the pelvis during functional tasks by resisting external forces. NMR approaches have successfully increased strength and postural stability (McKeon et al., 2008; O'Driscoll and Delahunt, 2011), gait kinematics (McKeon et al., 2009), and movement patterns, while also reducing the risk of injury in other populations such as patients with ankle injury and anterior cruciate ligament reconstruction (Hewett et al., 2006; McKeon and Hertel, 2008).

Neuromuscular reeducation exercise program focused techniques emphasizing use of the hip abductors to stabilize the pelvis, thus improving movement quality to maximize functional recovery. Specific weight-bearing exercise aimed at improving hip abductor performance and pelvic stability was included in these techniques. Participants worked their way through bilateral, then unilateral weight-bearing exercises that comprised both static and dynamic functional tasks. The therapist closely monitored these actions and gave verbal, visual, and tactile signals to maintain pelvic stability. These strategies were also employed to encourage the usage of hip abductors as a means of maintaining a horizontal pelvic alignment during task performance. The progression of these activities was determined by the participant's ability to achieve the necessary posture and movement quality. Participants were given visual, auditory, and tactile cues to help them maintain a stable, horizontal pelvis during gait and running training sessions.

NEUROMUSCUALAR REEDUCATION FUNDAMENTAL

The purpose of program used for movement analysis and determine the postural responses, movement strategies, and appropriate feedback. Then connect and transfer the skills and abilities to address the missing components of normal movement. NMR encouraged the person to participate in new movement, transfers to activities of daily living throughout function exercise. When repeat practice in vary of situation for maximize the adaptability.

Decision-Making Framework for Selecting Intervention (Fell, 2004) stablished a clinical decision-making framework for selecting and advancing therapies in this population All interventions commonly used in this population (for example, gait and locomotion training, functional training, balance and coordination training, conditioning, and reconditioning) can be chosen and progressed based on clinical decisions that fall into one or more of the following three categories: Progressing function through motor learning principles (type of practice: components, variety; feedback: extrinsic to intrinsic; environment:closed to open, simple to complex.

Progressing function through addressing characteristics of movement / task. (Amplitude, velocity, amount, endurance and single to multi-joint motions). More adaptive in other parameters (developmental sequence, supportive and assistive devices and level of assistance: physical, verbal cues)

4.2 SINGLE LEG SQUAT (SLS)

According to Bishop, Brearley, Read, and Turner (2016), the single leg squat (SLS) is an exercise that has been the topic of multiple research investigations in recent years - largely in the former physiotherapy and sport rehabilitation fields, given where the majority of material has been published. The unilateral character of the exercise has prompted academics and practitioners to identify the primary muscles involved in this movement pattern, as well as the factors that may be important for improving performance during this specific task.

Distefano, Blackburn, Marshall, and Padua (2009) examined muscle activation of the gluteus maximus and medius in 21 in 21 healthy subjects during 12 commonly used bodyweight exercises within the former times of rehabilitation. Table 2 shows the effects of muscle activation.

The findings of Boudreau et al. (2009) who evaluated the electromyography (EMG) during the SLS, lunge and step-up-and-over exercises, support these finding. The SLS significantly increased activation ($p \leq 0.017$) in the rectus femoris (26.7%), gluteus maximus (35.2%) and gluteus medius (30.1%). Even though EMG values were significantly lower than DiStefano's, the trend of muscle activation followed the same pattern when comparing the assessed workouts.

Exercise	Glute Maximus	Exercise	Glute Medius
Single leg squat	59 ± 27	Side-lying hip abduction	81 ± 42
Single leg deadlift	59 ± 28	Single leg squat	64 ± 24
Transverse lunge	49 ± 20	Lateral band walk	61± 34
Forward lunge	44 ± 23	Single leg deadlift	58 ± 25
Sideways lunge	41 ± 20	Sideways hop	57 ± 35
Side-lying hip abduction	39 ± 18	Transverse hop	48 ± 25
Sideways hop	30 ± 19	Transverse lunge	48 ± 21
Clam (60° hop flexion)	39 ± 34	Forward hop	45 ± 21
Transverse hop	35 ± 16	Forward lunge	42 ± 21
Forward hop	35 ± 22	Clam (30° hop flexion)	40 ± 38
Clam (30° hop flexion)	34 ± 27	Sideways lunge	39 ± 19
Lateral band walk	27 ± 16	Clam (60° hop flexion)	38 ± 29

Table 2 Normalized gluteus maximus and medius mean and standard deviation signal amplitude expressed as a percentage of MVIC.

Source: DiStefano et al. (2009)

Finally, gastrocnemius activity was 2.5 times higher in female individuals than in males, which, when combined with increased quadriceps activation, suggests that the females in this study may have employed a more 'knee dominant' movement pattern to perform the SLS. Using a 'hip hinge' method has previously been observed in optimal squatting mechanics; consequently, coaches should always be mindful of ideal movement mechanics when observing their athletes' technique.

There is also the issue of motor control when it comes to improving SLS performance. It is best to create the required motor pattern for a given job; otherwise, the musculoskeletal system would likely use all available possibilities to self-stabilize and maintain symmetry. According to existing literature, the coach is advised to base their coaching strategies around the intention-action model and intrinsic knowledge of results (Wulf, 2013). An in-depth explanation of these models lies outside the scope of this article, but these outcome-based approaches have been found to be a useful method for enhanced motor learning (Schmidt et al., 1990). For example, during the SLS activity, the coach may constrain the athlete to a more hip dominant pattern by placing a barrier in front of their shins, reducing forward motion of the shank. Alternatively, the athlete could be urged to resist hip adduction by imposing a medial resistance, which should prompt the brain to adopt a counterstrategy by forcing the knees out. These are just two examples of drills that the authors of this article have found to be useful in practice, but it should be noted that a range of drills is likely to elicit best learning and retention

The clinical assessment of the single-leg squat may be capable of identifying patients with hip muscle dysfunction and hence may be a tool that can be used by clinicians when selecting treatment options (ei, strengthening or retraining hip muscle function) targeted to their patients' findings. In addition, these results may be used in clinical research to establish subgroups of people with hip muscle dysfunction and evaluate targeted treatments The Single Limb Squat (SLS) is a clinically reliable tool (80-87% agreement, K = 0.700-0.800) to identify people with hip movement dysfunction (Crossley, Zhang, Schache, Bryant, & Cowan, 2011).

The single-leg squat (SLS) and single leg landing (SLL) movement are frequently used tasks to assess lower alignment (Davis & Futrell, 2016; Dawson & Herrington, 2015). SLS and SLL have biomechanical and neuromuscular similarities to a wide range of athletic movements and thus are involved in rehabilitation program of different sports designed to prevent injuries and enhance athletic performance (Davis & Futrell, 2016; Dawson & Herrington, 2015; Willson et al., 2005; Willy & Davis, 2011). All kinematic and kinetic variables acquired from healthy subjects during single leg squat and landing activities demonstrated good to exceptional consistency, with relatively low standard error of measurement values. These findings are important for practitioners who use single legged squatting and landing because they establish the task's reliability and measurement error for future screening and prospective research for injury prevention and rehabilitation strategies.

The SLS kinematics are presumed similar to the lower extremity kinematics in the single leg stance phase of running, as the single leg is supporting the body weight, and also undergoes knee flexion during the stance phase of running. Hence, the SLS is used to simulate a phase of running that might be contributing to anterior knee pain symptoms. Many studies have utilized this task to evaluate lower extremity alignment in patients with PFPS (Hollman et al., 2009; Zeller et al., 2003). As single limb squat kinematics are related to hip muscle dysfunction, and also used as a tool to assess rehabilitation status, it is important to have a clinical rating criteria that is reliable among raters (Crossley et al., 2011).

The single limb squat is a unilateral weight bearing task, where the stance knee is bent to a certain degree, while the other leg is hanging in the air. This is also similar to the single limb step-down or single limb descent, as in these conditions, the stance leg is supporting the body weight and undergoing a squat like bend in the stance leg. Thus, previous literature about these tasks was considered in combination to shed light on the relationship between hip and knee kinematics and hip muscle function.

Claiborne et al., (2006) studied healthy adults while they performed the SLS and compared their kinematics using a Falcon system and hip muscle strength using a

Biodex Isokinetic dynamometer. The hip abduction, hip adduction, hip flexion and extension concentric and eccentric strength were tested at an angular velocity of 60 °/sec. The peak torque for each of these variables was obtained. When a linear regression analysis was performed, it was found that concentric hip abduction (r^2 = 0.13), knee flexion (r^2 = 0.18), and knee extension (r^2 = 22 0.14) peak torque were significant predictors ($p < 0.05$) of frontal plane motion of the knee (peak knee abduction minus standing frontal plane motion of the knee) during a SLS (Claiborne et al., 2006). A moderate, significant relationship was found when a Pearson product moment correlation was conducted. Negative correlation was found between the concentric hip abduction ($r = -0.37$, $p < 0.05$), knee flexion ($r = -0.43$, $p < 0.001$), and knee extension ($r = -0.37$, $p < 0.05$) peak torque and frontal plane knee motion. Thus, Claiborne et al., were able to bring out the relationship between strong hip abductors and decreased movement of the knee towards an abduction direction (Claiborne et al., 2006). Similar findings were seen in a study by Crossley et al., who compared people who performed “poorly” in the SLS to those who performed “good”. The authors discovered that those regarded as strong performers had larger hip abduction torque than persons evaluated as bad performers (mean difference, 0.47 Nm/Body Weight; 95% CI, 0.10-0.83 Nm/Body Weight). Differences between the two categories of SLS performers were also seen in the electromyographic activity of the anterior and posterior gluteus medius muscles. Subjects who scored “good” on the SLS had significantly earlier onset timing of anterior gluteus medius (mean difference, –152 ms; 95% confidence interval [CI], –258 to –48 ms) and posterior gluteus medius (mean difference, –115 ms; 95% CI, –227 to –3 ms) electromyographic activity.

Biomechanical Model

Contralateral Pelvic drop – Pelvic drop relative to a laboratory reference frame provides information about the position of the ASIS and the PSIS, as well as results in hip adduction. Pelvic drop is a measure of pelvic movements in the laboratory reference frame and is also referred to as pelvic obliquity. During a single limb squat or single limb stance phase of running, the center of mass has to be contained over a narrow base of support, as the person is standing on a single foot. To accommodate this, a person may use different techniques to maintain balance. The techniques can be the knee moving into abduction coupled with hip (femoral) adduction while maintaining a level pelvis. A different strategy can be the pelvis dropping on the contralateral side coupled with hip adduction, but not increasing the knee abduction. Hence, it is not clear if pelvic obliquity is always coupled with knee abduction. However, since it's only known biomechanical impact would be in altering knee abduction, and knee abduction is already being directly measured, It will not be included in the model. The variables to be utilized to examine the relationship between single limb squat and running are discussed below. Single limb squat is a clinical tool commonly used to assess runners with knee pain. In some cases, because of ease of visual assessment, clinicians are using a single limb squat instead of examining running mechanics to indirectly assess the mechanics that may cause knee pain.

Hence, this hypothesis is to study if single limb squat and running mechanics are similar. Common variables visually examined during a single limb squat are pelvic drop, hip adduction and knee abduction. In addition, hip internal rotation is of interest, though less easily assessed visually. Hence, according to the hypothesis, knee abduction excursion, hip adduction excursion and hip internal rotation excursion during single limb squat will be related to knee abduction excursion during running. The reason for selection of the single limb squat variables is discussed below. Based on the biomechanical model and literature (Hewett et al., 2006), there is likely to be association between, hip adduction during single limb squat and Q-angle. If statistical analysis confirms significant correlations (r >0.7) between hip adduction during SLS and Q-angle, then the variable that will be entered in the relationship regression model will be hip adduction. This is due to the reasoning that Q-angle is a static variable and not measured during the dynamic activity of interest. Hip adduction during SLS is also important to consider in this regression model (but not the pain regression model) as it provides information about how much hip movement is contributing to knee abduction apart from tibial movement and foot pronation. Hip internal rotation during SLS is also of primary interest with regard to the likely influence on the position of the patella with respect to femur. Knee abduction excursion during SLS will also be a variable of interest as it takes into account the movement of the tibia, but it will also likely be correlated with hip adduction angle. If the knee abduction and hip adduction are highly correlated (r> 0.8), then knee abduction will be applied in the model, as knee abduction takes femoral adduction into consideration. This model takes into account mainly the variables related to the hip. This is due to the reasoning that weak hip abductor strength has been associated with knee pain (Niemuth et al., 2005; Souza & Powers, 2009). If it is demonstrated that hip kinematics are strongly associated with knee abduction, we can support the considering hip interventions to prevent or treat knee pain.

Then, muscular imbalances (agonist-antagonist and synergist) can impair lower extremity function by increasing hip adduction, knee abduction, tibia internal or external rotation, eversion, pronation, and restricted ankle dorsiflexion. This can also increase dynamic knee valgus and the amount of strain on the ACL ligament. Normal muscular co-contraction can improve coordination and prevent joint instability and lower extremity injuries (Saki, Tahayori, & Bakhtiari Khou, 2022).

4.4 MOTOR SKILL LEARNING AND PRACTICE APPLICATION

4.5.1 Feedback

The term "feedback" refers to when performers receive sensory information regarding their actions. Feedback can come from a variety of places and can have the following effects: reinforcement of the proper or desired response, motivation of the performer to improve or maintain performance, and action correction as a result of knowledge regarding errors received. When feedback is removed, the performer's performance may suffer. Sources within the athlete may provide feedback. Internal or intrinsic feedback is the term for this. It can also come from outside sources, in which case it is known as external or extrinsic feedback. **Internal feedback** is information obtained organically through movement from the senses. The athlete is aware of his or her own legs, shoulders, arms, and fingers moving through the air when passing a basketball. The athlete can see and hear the ball leave his fingers and being caught by a partner. Without the aid of technology, gadgets, or other people, the athlete perceives information regarding his or her performance. As a result, internal feedback includes performance-related experiences (such as visual, audio, haptic).

External feedback refers to information received from sources other than the performer's innate sensory knowledge of the current activity. The coach's voice, the scoreboard, video analysis, or the crowd's cheer can all provide external input. Two important forms of feedback are **knowledge of results (KR) and knowledge of performance (KP).** The knowledge of results is data that is communicated to others after an activity has been completed. It is determined by the performance's outcome or the factors that contributed to the outcome. When learning a new skill, it is very beneficial. KR enables a learner to rectify an action the following time, to be reinforced when an effort is completely or partially correct, and to stay motivated to try again. Examples of KR include a gymnastics score and a coach's reaction to his or her team's performance.

The knowledge of performance is information about the movement that is received either internally or externally. KP keeps quiet about the movement's achievements (as KR does). Rather, KP informs about the movement pattern's performance, or how it seemed. For example, a gymnastic coach telling a gymnast that she had nice body shape and height during a movement or that her feet came apart has no bearing on the gymnast's score.

Timing of feedback, there are several options for athletes to obtain feedback before, during, and after a performance. **Concurrent feedback** is when you get feedback as you're performing. The sensation of a ball hitting a table tennis bat or the sight of the goalie shifting to the left before a penalty shot are two examples. At the time, the athlete can reply to the contemporaneous input. **Delayed feedback** (also known as terminal feedback) is given after a performance and is thus too late to elicit a reaction at the moment. Internally and externally, both concurrent and delayed feedback can be delivered. Concurrent feedback and other activities between performances may obstruct learning by diverting the learner's attention away from the movement being done.

4.5.2 Whole and part practice method

The whole-or-part approach is another way to practice. This technique specifies whether abilities should be performed in sections or in their whole. Should a softball hit, for example, be taught as a whole or in sections, such as stance, grip, swing, and follow-through? In each particular case, one way will be more successful than the other, but a decision must be taken, and when presents the notions of task complexity and task organization to assist in this selection. A number of part or component parts present, as well as the activity's intellectual demands, determine **task complexity**. The task complexity of a dancing routine is high, but the task complexity of weightlifting is low. The interrelationships between the task's component pieces are referred to as **task organization**. Because the components of a jump shot in basketball are interconnected and highly dependent on one another to reach the goal, there is a high degree of task organization. Because the order in which the sections are performed is not always tied to attaining a defined goal (such as scoring a goal) in the entire performance, dance has a low degree of task organization.

It's hard to put the above knowledge into practice since not all talents are at the same level of complexity and organization. As a result, predicting which approach to utilize is difficult. Some talents are in the center of the spectrum and may require a combination of approaches. It's not unusual to employ a mix of whole and part practice (learning skills in whole and part at different periods) or progressive part practice.

Progressive part practice is a word that describes learning individual bits of a complicated ability and then combining them to produce larger and larger sections until the entire skill is performed. Spikes in volleyball, for example, may be broken down into run up, stepping, leaping, and striking. Each skill is trained alone before being added to the others until the full talent is practiced. For beginners or while learning a new talent, part practice is beneficial.

Finally, the ability to teach your body to learn and perform different things is the foundation of motor learning and motor control. The sooner you begin programming the proper technique to perform certain motions such as running, jumping, throwing, lifting, and so on, the better student or athlete you will be. The most critical part is to master appropriate technique as soon as possible since the longer an athlete waits, the more likely he or she will develop undesirable habits.

The researchers looked at how adults and adolescents without impairments reacted to visual kinematic input aimed at changing the motion of one hip or knee joint while keeping the typical patterns in the contralateral and ipsilateral hip and knee joints during walking. (Oliveira, Ehrenberg, Cheng, Blochlinger, & Barrance, 2019). Overall, the statistics revealed that adults outperformed teenagers in the novel. The study implies that adults and adolescents adopted different techniques, with adults demonstrating greater awareness of the requirement and/or capacity to limit mistakes in the contralateral leg at the start of the activity. Furthermore, adults outperformed adolescents in terms of retaining lesser mistakes in the ipsilateral hip or knee with the unmodified target, for both hip and knee feedback. These differences could be due to adults' ability to use an internal representation of the task, which could be useful during our short-term feedback task; or they could be due to the nature of our session, which relies on continuous modifications during the task (rather than short rest intervals), which has been shown to benefit adults. Overall, research indicated that whereas teenagers focused on improving the joint with the modified target - specifically the modified parts - adults also worked to reduce mistakes in joints with unaltered target patterns.

The important implications to the design of feedback techniques directed at the hip or knee joints. When introducing a new joint pattern during gait that requires adaptations from the ipsilateral joint, it is important to determine which joint pattern is more stable. The particular features of a system's coordination dynamics affect the transition to new motor patterns. To be able to modify a specific motor pattern, the individual must first destabilize the current pattern and then switch to a new one - and the more stable the current pattern is, the more difficult it will be to destabilize.

Therefore, feedback interventions directed at hip or knee flexion patterns should consider longer practice periods when the hip is being targeted.

Fitts & Posner (1967) proposed three phases of skill development including perceptual-motor learning components: cognitive, associative, and autonomous. Our findings show that participants are in a stage of the learning process that involves short-term gains in performance (although with significant deviation from the task aim) and the capacity for instant retention. Because participants did not completely complete the task, it shows that the cognitive stage was still involved in selecting 'what to do,' finding useful feedback cues, and creating acceptable movement attempts that satisfied the task restrictions.

Typical of a stage of learning (Fitts & Posner, 1967). This might be because of our feedback testing procedure: 1) We did not include a resting break between the feedback block and the retention test, and 2) participants were informed of the remaining time during the experiment. As a result, during the feedback test, participants may have developed a strong enough internal representation of the task that may be employed immediately after feedback has been removed without causing warm-up reduction. These findings imply that feedback techniques that eliminate or lessen the concentration demands associated with feedback interpretation may be advantageous. Furthermore, the data show that the feedback dose delivered was insufficient for learning the desired pattern, and that longer feedback exposures via longer sessions or several sessions should be studied.

The goal of this study was to see if individuals could shift their hip or knee gait pattern to a modified pattern while keeping their other joints' flexion patterns the same. This gave similar task circumstances to hemiplegic gait feedback trials. An incongruent task is one that requires distinct difficulty indices on both sides. Incongruent activities have been proven to enhance cognitive demands and create some interdependence between the parties. This study is significant because it emphasizes the difficulties of such activities, especially for children. A modified segment and a baseline section were incorporated in the modified target for the hip and knee.

4.5.3 GAIT RETRAINING

While changing a motor pattern may be desirable, it will almost certainly change the demands on the musculoskeletal system. Retraining a runner to contact the ground with the forefoot in order to avoid vertical impacts, for example, lessens the strain on the knee but increases the burden on the calf. To limit the danger of an overuse injury to the calf muscle, it is necessary to strengthen it. As a result, any gait retraining solution should incorporate a particular strengthening program to anticipate greater demands on other components of the kinetic chain (Davis and Futrell, 2016).

Jeon and Thomas (2019) Feedback motion retraining was found to be useful in improving gait biomechanics, discomfort, and self-reported function in individuals with PFP. After eight sessions (15–30 minutes each) of feedback gait retraining, the researchers found persistent improvements in abnormal gait kinematics. In all of the trials considered, providing a mix of mirror, script, and extra verbal feedback during motion retraining improved not just biomechanics but also discomfort and self-reported function. As a result, incorporating the aforementioned modes of feedback to reduce hip adduction, internal rotation, knee valgus, and contralateral pelvic drop while increasing ankle plantar flexion and range of motion appears to be beneficial to patients with PFP, particularly those with faulty movement patterns.

The gait retaining using real-time feedback improves hip mechanics and reduces pain in subjects with Patellofemoral pain syndrome according to Noehren, Scholz, and Davis (2011). They discovered that in participants with PFPS, real-time gait retraining resulted in improved hip mechanics, a significant reduction in pain, and an increase in function. When planning an intervention, gait retraining for persons with poor running mechanics should be considered. While jogging, there was a considerable reduction in HADD and contralateral pelvic drop. HIR fell by 23% after gait retraining, which was not statistically significant. The 18% reduction in HADD during a single leg squat was very near to statistically significant. Significant improvements in pain and function were also observed. At a 1-month follow-up, subjects were able to sustain their improvements in running mechanics, discomfort, and function. The retraining resulted in an 18% and 20% reduction in immediate and average vertical load rates, respectively.

Recommending long-term gait retraining to non-injured runners in order to prevent injury is a more difficult proposition. We would essentially propose runners comply to a pattern that aims to minimize specific biomechanical stressors without having the symptom history to guide the strategy.

Wesseling et al. (2015) explored the extent to which hip and pelvic kinematics influence hip contact forces. The findings revealed that changes in frontal plane hip and pelvic kinematics had the greatest effect on the amount of hip contact forces, whereas changes in ipsilateral pelvic drop (pelvic obliquity) had an effect equal to changes in hip adduction. The hip adduction angle should be reduced to reduce hip contact forces, which may result in a wider-based gait pattern.

A narrower base of support, on the other hand, caused by increased hip adduction, can effectively increase hip contact forces. They also identified stride patterns that can be exploited to affect hip contact forces. The findings revealed that Trendelenburg gait did not improve joint contact forces.

Furthermore, contact forces associated strongly with early stance hip adduction and rotation moments. To anticipate contact forces in late stance, the combined hip adduction and flexion moments were required. These findings imply that gait training aimed at reducing hip adduction angles and consequent moments may minimize hip contact forces. The best retraining strategy for achieving generalizable change is unknown. Several recent studies have used multiple sessions in a laboratory setting over several weeks with verbal, visual, or audio cues and feedback.

FITT & POSNER THEORY (THREE STAGES OF LEARNING)

Motor learning may be roughly defined as a set of activities that attempt to acquire and perfect new abilities via practice. (Nieuwboer, Rochester, Müncks, & Swinnen, 2009). The corticostriatal loop and cerebellum's anatomical integrity and functional activity are crucial for motor learning processes. (Nieuwboer et al., 2009).

Individuals' capacity to acquire, practice, and re-learn motor skills has a significant impact on their ability to do any physical activity. As athletes develop their concentration practice, having some sence of the possible development stages can be useful. In this article, it reflects on the relevance of Fitts and Posner's (1967) stages of leaning model on motor skills acquisition.

1. **Cognitive Stage (Understand stage)**: Learners in the cognitive stage **(Understand)** are attempting to find out what precisely has to be done. The cognitive stage focuses on difficulties that are intellectually oriented, with the key concern being the ability to endure general features of a skill. Processing and understanding teacher instructions/feedback necessitates cognitive engagement. The learner develops a cognitive image of the skill and what is necessary to do it at this level. This stage's motions are jerky, sluggish, and poorly timed. The student is aware that something is wrong but is unclear how to rectify it, therefore performance is erratic. According to Fitts and Posner, while listening to instructions and receiving feedback from the teacher, the learner must participate in cognitive activity.

2. **Associative Stage**: The associative stage takes a long time to complete. In reality, the individual may never go past the associative level. The basics and mechanics of the skill have been mastered at this point, and performance is more consistent and less varied. Because the athlete has learned the capacity to notice and repair faults, there are fewer and smaller errors. As the athlete learns to employ environmental signals for timing, his or her movements become more **synchronized** and tailored to the job. As the individual has to think less about the skill and the shift to memorized motions occurs, **anticipation** increases, resulting in smoother, less hurried actions. With a significant reduction in energy expenditure, there is quick improvement. For example, a golfer will be able to make consistent contact with the ball, however the direction and distance will not be as constant as they will become.

3. **Autonomous Stage**: The skill becomes habitual or automatic after a lot of practice and experience. This is the self-contained stage. Improvements are sluggish at this point, although there is considerable consistency in performance. Because the

athlete requires less attention to the fundamentals, most of the skill is accomplished without thought. Instead, he or she may focus more selectively on higher-order cognitive processes like game strategy and external clues like the ball's spin or the opposition's location. The athlete has perfect timing and can recognize and correct faults as well as conceal actions. In performance contexts, this fosters self-assurance and risk-taking. For example, a golfer will be able to adjust his or her swing to fit the shot at hand, as well as curve the ball with control after hitting it to account for external elements like slopes and wind. The practice sessions in the autonomous stage must be well-organized to get the greatest results. The athlete has to be highly motivated and receive a lot of feedback. Training should try to replicate real-world performance situations. In this stage, psychological skills training may be quite beneficial, especially when coping with nervousness during contests.

RELATED RESEARCH

Earl and Hoch (2011) reported an 8week "proximal stability program" that includes five weeks of training emphasizing attention to lower extremity alignment during exercises for patellofemoral discomfort, researchers found that internal hip and knee abductor moments decreased by 15% and 23%, respectively, when running. Earl et al. support the idea that paying attention to lower extremity alignment may be a more important component of therapies used to change running mechanics than simply strengthening.

Judd et al. (2015) investigated the effects of neuromuscular reeducation on hip mechanics and functional performance in patients after total hip arthroplasty: a case series. The goal of this case series was to demonstrate how the application of targeted NMR methods after surgical recovery changed mobility strategy during everyday chores. Following total hip arthroplasty, ten participants underwent an eight-week exercise program emphasizing focused neuromuscular reeducation approaches highlighted by specialized, weight-bearing exercise to improve hip abductor function and pelvic stability. For comparison, five other subjects were monitored and followed.

The results demonstrated that while walking and stair ascending, participants in the neuromuscular reeducation program improved their internal hip abductor moments and vertical ground response forces. They also saw an increase in functional performance and hip abductor strength. Interpretation: Following complete hip arthroplasty, targeted neuromuscular reeducation strategies improved biomechanical results, functional performance, and muscle strength. Increased internal hip abductor moments were seen after concentrated exercise of the hip abductor muscles. This intervention has the potential to enhance pelvic stability and performance on activities including stair climbing, quick walking, and balancing. The findings imply that neuromuscular reeducation has a distinct influence on movement strategy and function in total hip arthroplasty patients.

Noehren et al. (2011) investigated the effect of real-time gait retraining on hip kinematics pain and function in patients with patellofemoral pain syndrome, The goal of this study was to see if gait retraining using real-time feedback improves hip mechanics and decreases discomfort in PFPS patients. This research included ten runners with PFPS (male and female recreational runners, ages 18 to 45). Visual 3D was then used to process the data (Visual 3D Germantown, Maryland). An X-Y-Z Cardan angle rotation sequence was used to compute joint kinematics for each stance phase during treadmill running. The data from single leg squats was then processed in the same way as the data from running. During a single leg squat, we measured HADD, HIR, and contralateral pelvic drop. Kinematics of the single jointThe individuals received real-time kinematic input of hip adduction (HADD) during stance while running on a treadmill. Eight training sessions were completed by the participants. With the fading feedback design, input was gradually reduced throughout the last four sessions. Peak HADD, hip internal rotation, contralateral pelvic drop, discomfort on a verbal analogue scale, and the lower-extremity function index were also studied. The participants were instructed to tense their gluteal muscles and run straight forward while keeping a level pelvis.

There was a considerable reduction in HADD and contralateral pelvic drop when running after gait retraining. HIR fell by 23% after gait retraining, which was not statistically significant. During a single leg squat, the 18 percent drop in HADD was almost significant. In addition, pain and function both improved significantly. At a one-month follow-up, the subjects' gains in running mechanics, discomfort, and function were stable. An unanticipated advantage of the retraining was a drop in instantaneous and average vertical load rates of 18 percent and 20%, respectively. Gait retraining resulted in a substantial improvement in hip mechanics in people with PFPS, which was linked to a reduction in discomfort and better movement mechanics.

Wouters et al. (2012) investigated how a movement training program involving visual feedback, weekly teaching, and manual facilitation of lower extremity alignment influences hip and knee joint frontal plane running mechanics in females with altered weight bearing kinematics. After a four-week movement training program focusing on verbal and visual feedback as well as manual neuromuscular facilitation approaches, participants in this study showed decreased hip and knee abduction moments, increased knee adduction excursion, and decreased knee abduction excursion. The goal of the current study's intervention was to reduce the possible impact of exercise-induced muscle hypertrophy alterations. According to result of the study, peak hip adduction angle and contralateral pelvic drop did not improve at the end of a six-week program that included four weeks of visual and verbal feedback during standard hip strengthening activities. However, the results of their investigation did not reflect alterations in knee joint mechanics. The non-running workouts in the neuromuscular training program were developed to improve hip neuromuscular control in healthy female runners. While there was no change in hip neuromuscular control after the intervention, the peak hip adduction angle while running remained intact.

CONCEPTUAL FRAMEWORK

Study 1 This study use the whole correction training and part correction training to fix and adjust the particular specific skills of running but there is no prior research that directly compare the benefits of the two training techniques. Therefore, we would like to see how both methods, part correction training and whole correction training, perform when approaching with a randomized pretest posttest control group design. Not only for efficiency, but also to see if alternating sequences would lead to a different outcome.

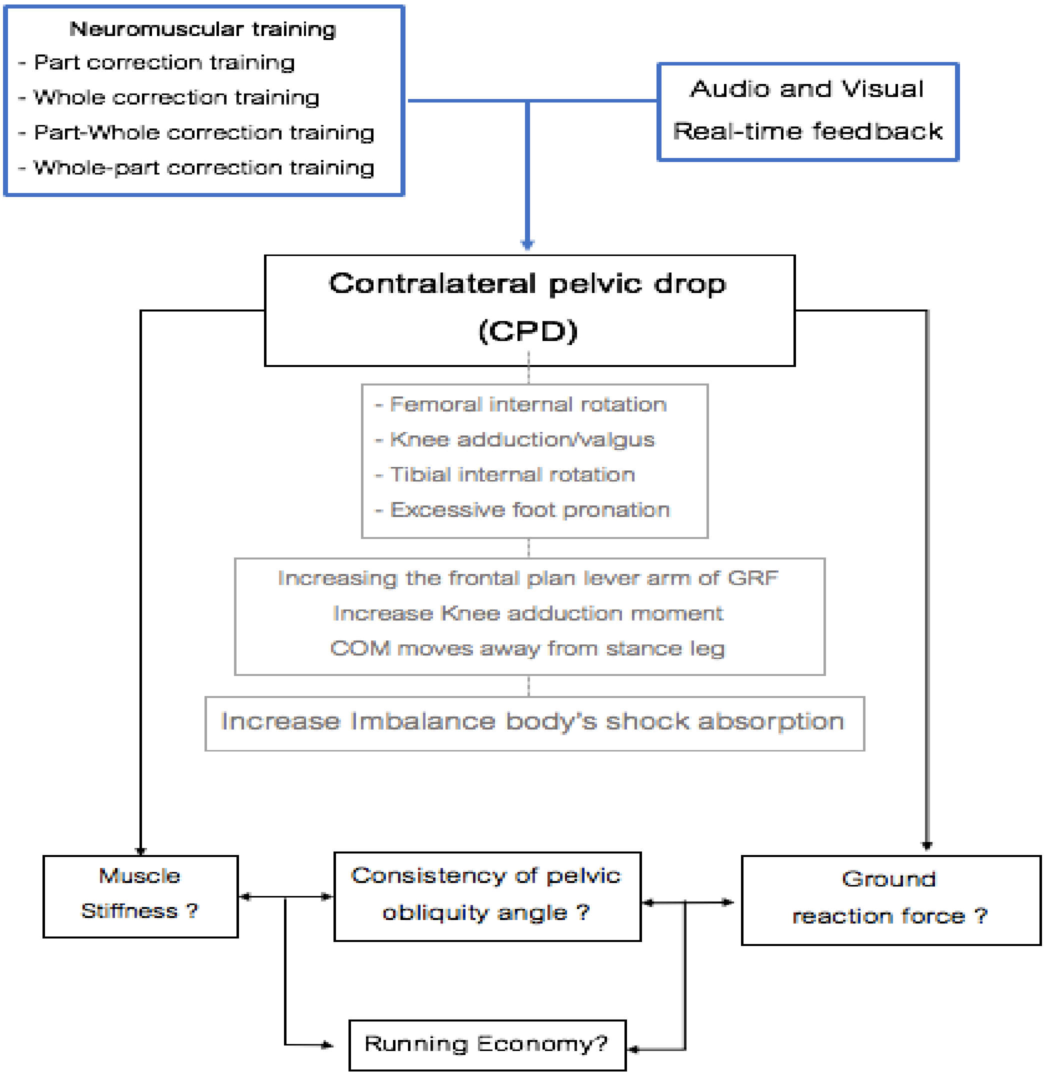


Figure 4 Conceptual framework of Study 1

Study 2 This study will study the retention effects of every method; whole correction training, part correction training and the combination of both are to be studied to analyze which method is the most effective in the shortest period on contralateral pelvic drop and running economy in long-distance recreational female runners.

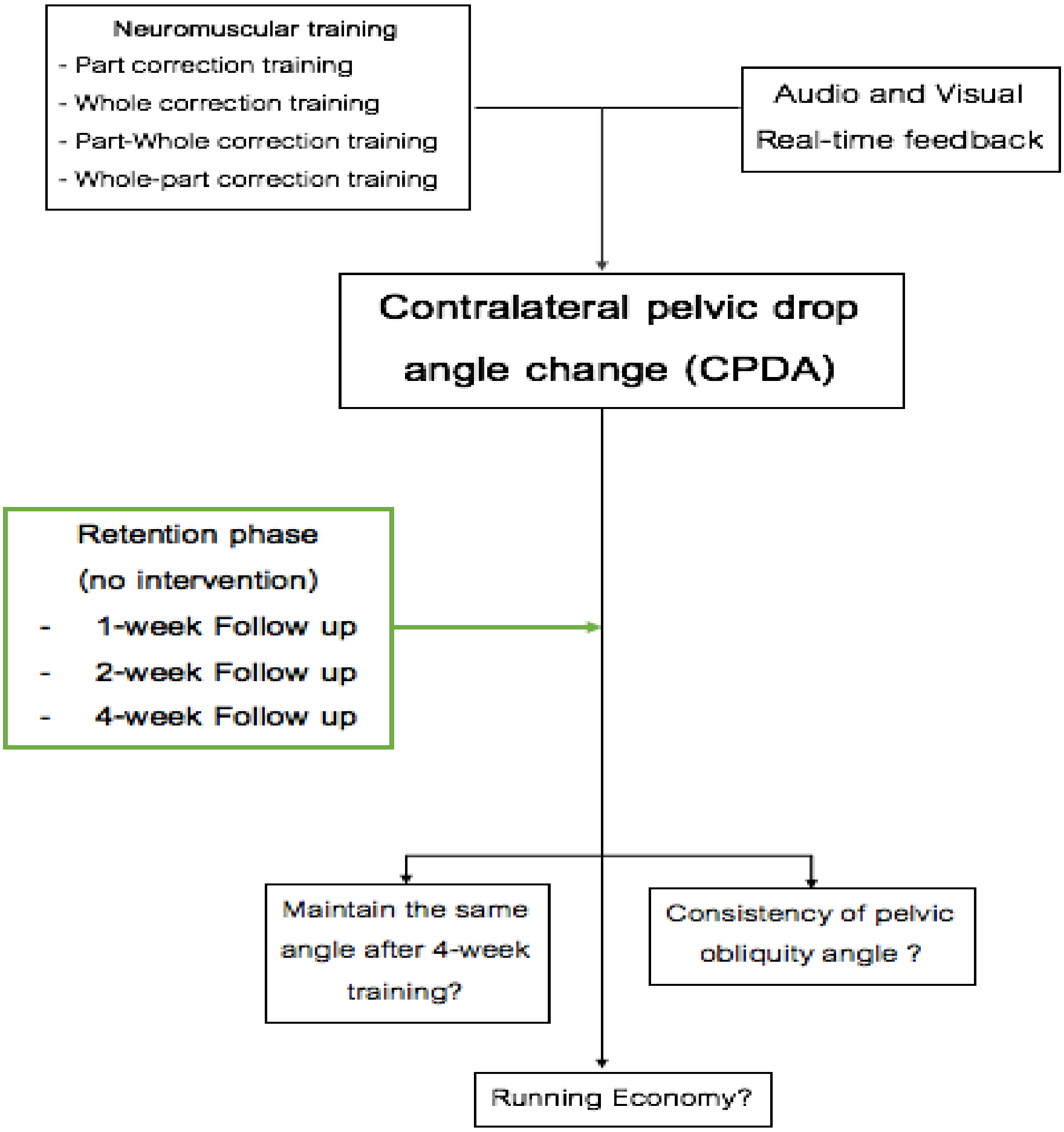


Figure 5 Conceptual framework of Study 2

CHAPTER 3

STUDY 1

EFFECTS OF NEUROMUSCULAR TRAINING PROGRAM

The study 1 focused on comparing the effects of neuromuscular training program among part correction training, whole correction training, a combined part-whole correction training and a combined whole-part correction training on contralateral pelvic drop and running economy in long-distance recreational female runners.

PARTICIPANTS

Participants from the Samitivej running club were invited for a screening test. Participants were all recreational female runners age between 24 - 45. The rationale of recruitment the research participants age between 24 – 45 was that age played an important part in injury in women: being over 50 years old was a risk factor for overall injury. Moreover, women age between 24 - 45 were in their reproductive age. The body growth, bone density and development physiological were more stable

All participants were given an informed consent in accordance with The Research Ethics Review Committee for Research Involving Human Research Participants, Health Sciences Group, Chulalongkorn University and then completed a self-report running questionnaire regarding their general health and running. The questionnaire (Appendix A) was to be used as a screening tool to establish whether the participants fitted the guidelines of the inclusion and exclusion criteria.

Sample size was calculated based on expected changes in frontal plane running kinematic. Using a similar 4-week multimodal neuromuscular intervention, a previous study (Wouster et al., 2012) reported decrease in frontal plane running kinematic of greater 2.7° in 4-week training. We determined that 8 participants per group were necessary to considering similar outcome change, α = 0.05, power = 0.80 and effect size >0.7 (G*power 3.1.7). Adding an anticipated attrition rate of 15%, 10 runners per group were recruited. Then the purposive sampling used to assemble the participants with similarity in oxygen consumption (VO_2max) that was previously tested. The participants were divided into 4 groups as follow.

- Group 1: Part correction training (PCT; n=8)
- Group 2: Whole correction training (WCT; n=8)
- Group 3: Part followed by whole correction training (PWCT; n=8)
- Group 4: Whole followed by part correction t training (WPCT; n=8)

Inclusion Criteria

1. Participants were recreational female runners age between 24 – 45 years of age that regularly run at least 10km/week but not over 30 km/week.

2. Participants had no history of cardiovascular disease, neurological or cognitive diseases that would impair motor functioning to follow instructions by questionnaire of injury history.

3. Participants had no musculoskeletal disease, recent history of musculoskeletal injury and lower limb and back surgery within the past year and able to walk independently by questionnaire of injury history.

4. Dynamic pelvic drop test (Appendix C). To assess dynamic pelvic drop test, flat markers (9 mm in diameter) were placed at both sides of Posterior Superior Iliac Spine (PSIS). They were asked to run for 30 minutes on treadmill (Sprintex Natural movement, USA) with Base run (runner's natural pace). Digital video cameras (Sony, Tokyo, Japan) were placed on stand at the back and side of participants and horizontal images were recorded at 30 HZ. The center of back and side camera lens was adjusted to the height of the hip of participants while standing on the treadmill. The researcher recorded the contralateral pelvic drop angle during the last five running cycles every 10 minute and proceeded to evaluate the average angle of pelvic drop during midstance phase by the Kinovea software 0.9.4 version (Kinovea, Korea). The midstance phase was from the lateral malleolus of the swinging leg parallel with the marker on the Lateral Malleolus of the stance leg. If the average pelvis dropped over 5° from PSIS line during running on the non-weight bearing side, the participants were assessed as positive (Huntley, 2003)

5. Participants leg length difference between 2 legs must not be over 1.5 cm.

6. Participants were allowed to participate in the research by physicians.

Exclusion Criteria

1. Participants were unable to participate, ex. Illness, injury, accident etc.

2. Participants requested to withdraw or participate in the training session less than 80% (12 of 16 times).

THE PROTECTION OF PARTICIPANTS

The protection of participants starting with self-introduction, then explaining the objective of the research including the benefit that participants will receive. Participants will be informed that full cooperation is required throughout the whole process. Participants will always have the right to reject or withdraw without any condition. The researcher will tend to each participant closely from the beginning to prevent any risk of injury that might occur during practice of gait retraining and neuromuscular training. In any case of soreness or pain, first aid procedures will be applied accordingly. If there ever be a chance of hospitalization, researcher will see to it that participant receives the proper treatment for the symptom.

PROCEDURE

1. Review literature and research related to contralateral pelvic drop. The research of neuromuscular training, etiology of female runners and running economy are also reviewed.

2. Study and analyze the neuromuscular training to design the most effective program suitable for correcting contralateral pelvic drop in long-distance recreational female runners. The training programs had been evaluated by 5 experts as stated in Appendix G. The IOC valued of neuromuscular training program 0.96. Moreover, the one research assistants were recruited with sport science

3. Conducting 40 participants by coordinating with the president of the Samitivej running club. Then recruit the most suitable participants following the inclusion

criteria. The participants must be willing to participate in every procedure throughout the entire process.

4. Participants were explained about the purposes and procedures of the research and given the informed consent. They had to fulfill all the questionnaire about their general information— age, weight, height, body composition and health history. Each participant would be measured their body composition and body weight by body composition analyzer that use bioelectrical impedance analysis (Bishop et al., 2016) to show bodyweight and percentage of body fat of each. Body height would be measured by height meter in centimeter.

5. Collecting the initial assessment data of the experiment, contralateral pelvic drop, maximal oxygen consumption and velocity at VO_2max, running economy ,isokinetic strength test and lever arm length. This testing procedures are to be collected at the same location, with researcher and research assistant who was a sports science officer closely supervised throughout the test. Each testing session required participants to perform isokinetic of hip abduction-adduction (HBD-HDD) test, contralateral pelvic drop angle (CPDA) test, and running economy test (RE). The testing session took 2 days in order to ensure maximum performance and minimum fatigue due to tests. The participants performed HBD-HDD test on the first day in order to measure hip muscle strength. To ensure the participants had enough rest, the second day of testing was scheduled to be 24 hours from the first day. CPDA test followed by RE test with a 10-minute interval rest was performed on the second day. The participants performed a VO_2max test after HBD-HDD test at pretest to find the velocity at VO_2Max for training. The participants were asked to get enough rest and avoid strenuous exercise on the day before the test sessions. They were also asked to refrain from smoking and drinking caffeinated and alcohol at least 3 hours prior to the tests.

5.1 Evaluation of isokinetic strength testing of hip muscle

All participants were instructed to wear cool and loose clothes and their shoes must be taken off. Other than refraining from eating or drinking for 3 hours before testing, they were also asked to refrain from caffeine or doing heavy physical activity for 24 hours before testing Prior to the test, the participants were asked to warm up using 5-minute cycling with freeloading and constant speed and dynamic stretching 5 minutes before testing, this should be done by concentrating on the lower body part. The duration of the session will be approximately 30 minutes. The location of testing is the exercise and sports performance laboratory at faculty of sports science, Chulalongkorn university.

The muscle strength of the gluteus medius was measured using isokinetic dynamometry (Biodex System 4 Dynamometer, Shirley, NY, USA). Since the main purpose of this study was to compare the neuromuscular adaptations after training, isokinetic test helped reduce confounding factors due to increases in strength. The test was evaluated for two different types of muscle action, i.e., concentric and eccentric. To evaluate hip strength of concentric and eccentric, 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. The participations were set up following the protocol by Lourencin et al., (2012). Prior to the test, the participants were asked to warm up using 5-minute cycling with freeloading and constant speed. After warm-up, they performed 5 preliminary familiarization trials at a very low intensity. The participants began the test when they felt ready after familiarization. The isokinetic peak torque was normalized to body weight (Nm/kg).

5.2 Evaluation of Maximal oxygen uptake (VO_2max)

All participants were instructed to wear cool and loose clothes and their own running shoes. Refrain from eating for 3 hours before testing. They are also asked to refrain from caffeine and heavy physical activity for 24 hours and from eating and drinking for 3 hours before testing. The duration of the session will be approximately 60 minutes. The location of testing is the exercise and sports performance laboratory at faculty of sports science, Chulalongkorn university.

A two-point calibration was used to calibrate the metabolic cart before and after each session, using room air and a gas mixture of known composition (4 percent CO2, 16 percent O2, balance N2). A manual 3-liter syringe will be used to calibrate the flow sensor (Hans Rudolf 3813 heated pneumotachometer). The manufacturer's accuracy values for O2 and CO2 are 0.03 percent and 0.1 percent, respectively, and 2 percent for volume. In our lab, the technical error of measurement for this system was 0.09 l/min (1.9 0.3 percent).

Starting test, the participants began running on the electric running track (HP Cosmos, Pluto, Germany). The tool for measuring physiological variables and running performance was incremental running test (Cardiopulmonary Gas Exchange System). Expired gases were measured a metabolic measurement cart (Cortex Metamax 3BR2, Breath by breath, Germany) for the determination of $\dot{V}O_2$ (ml·kg^{-1}·min^{-1}) and carbon dioxide output ($\dot{V}CO_2$, ml·kg^{-1}·min^{-1}). The protocol was adapted from Jones and Doust (1996). The protocol uses a 1% treadmill grade throughout testing session to reflect the energetic cost of outdoor running (Jones and Doust, 1996). The initial warm-up was 3 minutes at a speed of 6 km/h. The speed increased 1 km/h every 1 minute until volitional fatigue. Despite the constant encouragement of the evaluator, the test considered finished when the participants were unable to sustain the effort required during the test, show visual signs of volitional fatigue or want to stop the test due to strong discomfort. Once exhaustion was reached, the speed was reduced to 5 km/h for a 4-minute recovery period. Exhaustion was confirmed according to the following criteria: (1) presence of plateau in the O_2 consumption [maintenance of VO_2 values (± 2 ml.kg^{-1}.min^{-1}), despite the increase in exercise intensity]. (2) maximum value of heart rate (HRmax) $\geq$ 85% of HRmax estimated on age (220-age). (3) respiratory exchange rate (RER) values higher than 1.1.

Then, 30-s averages for VO_2, VCO_2, RER and HR were calculated. The highest 30-s value for VO_2 was recorded as VO_2max. The velocity at VO_2max (vVO_2max) was the minimal speed, sustained for at least 1 minute, at which the athlete run when VO_2max occurred. If an athlete achieves VO_2max during a stage that are not sustained for 1 minute, the velocity of the previous stage was recorded as vVO_2max.

5.3 Evaluation of the degree of contralateral pelvic drop angle

All participants were required to wear shorts and tight fitted clothes, were to use their own running shoes. Leukotape classic, a white tape with strong adhesive, used to strap down any area of the clothing that was loose. The participants started warm-ups with dynamic stretching 5 minutes before testing. The duration of the session will be approximately 30 minutes. The location of testing was the exercise and sports performance laboratory at faculty of sports science, Chulalongkorn university.

To evaluate **contralateral pelvic drop angle** during the midstance of stance phase, nine–camera motion capture system (Oqus 7+, Qualisys AB, Sweden) was applied to capture the range of motion of peak pelvic drop during running. Thirty-five retroreflective markers were placed bilaterally following the Qualisys PAF. Running Package Marker Set: above ear and glabella, acromial edge, medial and lateral femoral epicondyles, radius and ulna styloid process, aspect of the forefinger, anterior superior iliac spines, posterior superior iliac spines, medial and lateral malleoli, and head of the second metatarsal. For the foot, two markers were placed along the vertical bisection of the heel counter, one on the lateral aspect of the heel counter and one on the base of the fifth metatarsal. Additional tracking markers were placed on sacrum, manubriosternal edge, spinous process of the 2^{nd} and 12th thoracic vertebra and spinous process of the 12^{th} thoracic vertebra (Appendix B). The commercial software, Qualisys Track Manager (QTM 2.1.5 build 3300), which was an interface that allowed the user to perform 2D and 3D motion capture was used to acquire kinematic data during running with Visual 3D.

Nine motion capture cameras (sampling rate 200 Hz) were installed on the stand at a height of approximately 2.6 -3 meters along each side of the treadmill, and another two were placed lower and towards the front of the runner. Then calibrate the accuracy of the measurement until the average camera residual was approximately 1-2 millimeter or under. Each camera had collected at least 300 points. The standard deviation of the wand length should be 1-2 mm or better for a full body volume. Data reduction was completed with Performance Module Visual 3D (version 6.0.0., C-Motion Inc., Rockville, MD, USA).

After the markers were attached to the participants, the participants performed a 5-minute running as a warm-up. After that, they were instructed to run on a treadmill for 18 minutes where the participants ran for 6 minutes at 65% of velocity at VO_2max before running for 6 minutes at 75% and another 6 minutes running at 85%, respectively. The test procedure was similar to Fletcher et al (2009). Data during the stance phase of the last 6 minutes were collected to compute CPD angle because 85% of velocity at VO_2max was a sub-maximal speed the participants were able to maintain. The stance phase happened 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 in one minute. As a result, 72 CPD data points were collected into Visual 3D (C-Motion, Inc, Rockville, MD) and MATLAB software (Mathworks, Inc., Natick, MA). Marker trajectories data were low pass filtered at 10 Hz using 4th order Butterworth filter.

To calculate CPD angle, a vector calculation similar to Huntington (2018) was employed where CPD was an angle between pelvic plane and a transverse plane as shown in Figure 2. The pelvic plane was found from Sacrum, left ASIS and right ASIS. CPD angles were measured in degree, and the average value of CPD was used to further statistical analysis. The participants had a 10-minute rest before proceeding to RE test. All the angles and ROMs were measured in degrees (°) (Figure 9)

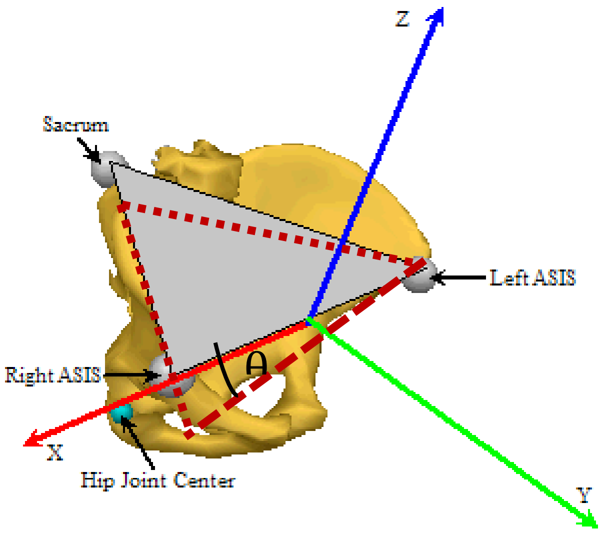


Figure 6 Contralateral pelvic drop angle was calculated by angle between two planes. The origin of the pelvis segment is the mid-point between the L_IAS and R_IAS markers. Together with the SACR marker, the two IAS markers define the orientation of the pelvis tilt. The CPDA was calculated from the declined degree of the ASIS, either left or right during single limb support in midstance phase.

Source: Qualisys, 2018

5.4 Evaluation of Running Economy

All participants were instructed to wear cool and loose clothes and their own running shoes. Refrain from eating for 3 hours before testing. They were also asked to refrain from caffeine and heavy physical activity for 24 hours and from eating and drinking for 3 hours before testing. The participant started warm-ups with dynamic stretching 5 minutes before testing. The duration of the session would be approximately 30 min. The location of testing was the exercise and sports performance laboratory at faculty of sports science, Chulalongkorn university.

The running economy testing procedure was similar to the protocol proposed by Fletcher et al (2009). In our study, it was not possible to perform RE test concurrently with CPDA test because running economy test requires the participants to run with a gas analyzer which was highly possible to impact CPD angle.

After the participants were equipped with a gas analyzer (Pluto med, H/P cosmos, Germany), the participants performed a warm-up by running at speed of 6 km/hr for 5 minutes. After warm-up, the participants ran for 6 minutes at 65% of velocity at VO_2max before running for 6 minutes at 75% and another 6 minutes running at 85%, respectively. The breath-by-breath VO_2 was averaged every 30-second. The average rate of O_2 consumption of the last two minutes when the participants ran at 85% of velocity at VO_2max was used to evaluate running economy.

The participants reached them RE steady state when an increase of O_2 was less than 100 ml during the first 4 minutes of 85% of velocity at VO_2max. VO2max value during the last two minutes of 85% of velocity at VO_2max was used to calculate running economy. If oxygen consumption was greater than 100 ml during the first 4 minutes, the participants were asked to continue running at 85% of velocity at VO_2max for two and a half minutes instead of two minutes as in the normal protocol. The VO_2max value from the additional 30 second was used to calculate running economy.

RE was calculated as follows:

$$\text{RE (mL } O_2\text{/kg/km)} = \frac{VO2\ (mL/min)\ x\ 60\ min/h}{Bm\ (kg) x\ running\ speed\ (km/h)}$$

where VO_2 was the average value of VO_2max during the last 2 minutes of 85% of velocity at VO_2max if oxygen consumption was less than 100 ml, otherwise, the average value of VO_2max during an additional 30 second of 85% of velocity at VO_2max was used. BM was the body weight of the participants (Skovgaard et al., 2018). Resting metabolic rate was not subtracted, because it cannot be confirmed that resting metabolic demand continues at the same rate during the running. This was a baseline subtraction issue as described by Stainsby and Barclay (1970).

5.5 Evaluation of lever arm of hip adduction moment during midstance

Since no kinetic measurements were obtained in this study, we use the lever arm length to clarify the change in CPD after neuromuscular training. Based on Change et al., (2005), decreasing in torque generation of the hip abductor muscle in the stance limb causes a contralateral pelvic drop. This drop shifts the body's center of mass toward the swing limb, thereby increasing forces across the medial tibiofemoral compartment of the stance limb. On average, there were 12 running cycles in one minute, As a result, 72 lever arm length data points were collected into Visual 3D (C-Motion, Inc, Rockville, MD) and MATLAB software (Mathworks, Inc., Natick, MA). Marker trajectories data were low pass filtered at 10 Hz using 4th order Butterworth filter.

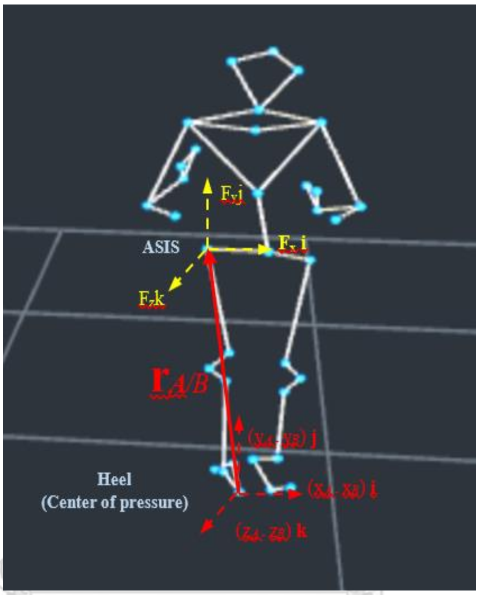


Figure 7 Lever arm length calculation during midstance phase.

To evaluate the lever arm length during the midstance of stance phase, a length calculation was calculated as follows:

3D Moment Vector: $\vec{M}_B = \vec{r}_{B/A}\ x\ \vec{F}$

Position Vector:

$$\vec{r}_{B/A} = (x_A - x_B)\hat{\imath} + (y_A - y_B)\hat{\jmath} + (z_A - z_B)\hat{k}$$

by Moment in 3D with an X-Y-Z sequence similar to Jenkyn et al (2008) was employed where the frontal-plane lever arm is the perpendicular distance from the marker on the heel to the marker on the ASIS of the contralateral pelvic dropped side (Figure 7). All the lengths were measured in centimeters.

6. Proceed to the **training program**. The participants were randomly assigned into four groups of different neuromuscular training program, i.e., part correction training, whole correct training, part-whole correction training, and whole-part correction training. Every group were trained for 4 days a week for 4 weeks (total 16 sessions). They were trained on Monday, Tuesday, Thursday, and Friday. Since our focus was only on neuromuscular training, the training period was 4 weeks in order eliminate potential influence of hypertrophic muscle changes on running mechanics (Moritani, 1979). The training was carried out by one technician with more than 8 years of experience.

At the 1st session, the participants were asked to run on the treadmill (Sprintex Natural Movement treadmill, USA) with their habitual running form at their natural speed for 3 minutes. During the running, the participants received no feedback. After finishing habitual running, the participants were asked to watch the video of their own running in frontal plane view. The researcher paused the video at the moment of foot contact and explained the movement pattern and running mechanics for the participants. After the explanation, the participants received an overall instruction of new movement pattern to improve their contralateral pelvic drop. The explanation and overall instruction were given only at the first session, then the participants followed the specific training method for each group without further explanation.

The training sessions in every group had similar pattern. The participants started the training session with a 5-minute dynamic warm-up followed by a specific training program for each group. During the warm-up, the participants jogged and performed joint mobility exercise. During the training session, the participants received both visual and verbal real-time feedbacks. The training program was designed to increase the training period while the feedbacks were faded as the training progress in order to promote acquisition and internalization of the new movement pattern and improve the persistence of the new movement pattern (Agresta et al., 2015). Over the course of 16 sessions, the training period was gradually increased from 10 minutes to 30 minutes. In each session, markers were taped to the right and left of posterior superior iliac spine.

The 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.

6.1 Part correction training (PCT): step single leg squat (SSLS) was performed in PCT. SSLS was selected due to its similarity to midstance phase during running. Moreover, SSLS training influenced lower extremity alignment and encourage hip and knee joint neuromuscular control (Bishop et al., 2016).

Upon arrival, the participants were attached with a marker tape on the right and left of posterior iliac spine (PSIS). After a 5-minute warm-up, SSLS was performed. The participants performed SSLS in front of a monitor. The monitor was connected to a motion analysis program (Kinovea software 0.9.4 version, Korea). The training program was presented in Table 3. 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 line of hip level through a monitor. Moreover, the participants were able to see a red line indicating if CPD was exhibited. The red line was created from Kinovea software. 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”

Table 3 Part correction training program 4-week training (4days/week); PCT

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

6.2 Whole correction training (WCT): While the participants in PCT performed SSLS, the participants in WCT perform running exercise as indicated in Table

4 The setup of WCT was similar to PCT where the participants were able to see if they experienced CPD through a monitor. Following verbal cues was provided for 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 4 Whole correction training for 4-week training (4 days/week); WCT

Week	%Velocity of vVo_2max	Rest/ set	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

The training programs **during the first two weeks** of each group were as follow.

Group1: *Part correction training (PCT)* followed the procedure of part correction training program (6.1), each session is performing as described in Table 4.

Group2: *Whole correction training (WCT)* followed the procedure whole correction training (6.2), each session is performing as described in Table 4.

Group3: *Part-whole correction training (PWCT)* was a combined part correct and whole correct trainings. The object was to compare the benefit of a combined training program. The participants in PWCT began their training with PCT for 2 weeks follow the program on week 1[nd] and 3[th] of PCT program.

Group4; *Whole-Part correction training (WPCT)* was a whole correct training combined part correct. The object was to compare the benefit of a combined training program. The participants in WPCT began their training with WCT for 2 weeks follow the program on week 1[nd] and 3[th] of WCT program.

7. Mid-test data collecting (after 2-week training) to compare the primary result of each training program on contralateral pelvic drop and running economy in long-

distance recreational female runners. The testing procedures were as described in the initial assessment (5.1 – 5.4) without Vo2max test.

8. Proceed to the training program. All participants were divided into 4 groups, each group were training for 4 days/week during the last 2 weeks. The part correction training and whole correction program were as described in 6.1 – 6.2.

The training programs **during the last two weeks** of each group were as follow.

Group1: *Part correction training (PCT)* followed the procedure of part correction training program (6.1), each session is performing as described in Table 4.

Group2: *Whole correction training (WCT)* followed the procedure whole correction training (6.2), each session is performing as described in Table 5.

Group3: *Part-whole correction training (PWCT)* was a combined part correct and whole correct trainings. The object was to compare the benefit of a combined training program. The participants in PWCT training with WCT for 2 weeks follow the program on week 2nd and 4th of WCT program.

Group4; *Whole-Part correction training (WPCT)* was a whole correct training combined part correct. The object was to compare the benefit of a combined training program. The participants in WPCT training with PCT for 2 weeks follow the program on week 2nd and 4th of PCT program.

9. Post-test data collecting (after 4 weeks) to compare the primary result of each training program on contralateral pelvic drop and running economy in long distance recreational female runners. The testing procedures were as described in the initial assessment (5.1,5.3 and 5.4) without maximum oxygen uptake testing (5.2).

10. Statistical analyze

11. Result and discussion of Study1

EQUIPMENT OF THE STUDY 1

1. Equipment of inclusion criteria

1.1 Questionnaire is divided into 3 sections (Appendix A)

- Personal and Running profile

- Injury Profile

1.2 Dynamic pelvic drop test (Appendix C)

1.3 Sprintex Natural Movement treadmill, USA

1.4 52 inches Samsung LED monitor, Korea

1.5 32 inches Dell LED monitor,

1.6 Running Analysis System, Kinovea program, French

2. Equipment of evaluation of contralateral pelvic drop angle

2.1 Motion analysis system Qualisys Track Manager (QTM 2.15 build 3300)

2.2 Performance module Visual 3D 6.0.0., C-Motion Inc., Rockville, MD, USA

2.3 Qualisys PAF running package marker set, Sweden (Appendix B)

2.4 Camera motion capture system Oqus7+, Qualisys AB, Sweden

3. Equipment of evaluation of Isokinetic strength test

3.1 Biodex System 4 Dynamometer, Shirley, NY, USA

4. Equipment of evaluation ofmaximal oxygen consumption ($VO_{2.}Max$) and running economy

4.1 Bioelectrical Impedance Analyzer, Jawon (OI 353 whole body,), Korea

4.2 Heart rate monitor, Polar (FT40), Finland

4.3 Breath by Breath Cardiopulmonary gas exchange system, Cortex (Metamax 3BR2 system), Germany

4.4 HP Cosmos treadmill, Pluto version, Germany

5. Equipment of training session (Appendix F)

5.1 Sprintex Natural Movement treadmill, USA

5.2 52 inches Samsung LED monitor, Korea

5.3 32 inches Dell LED monitor,

5.4 Running Analysis System, Kinovea program, French

STATISTICAL ANALYSIS

Statistical Package for Social Sciences (version 23; IBM, Armonk, NY, USA) was used to conduct all statistical analyses. A Shapiro-Wilk test was performed to determine if the data were normally distributed. Group demographics were compared using one-way analyses of variance (ANOVA) test in order to check if the demographics of each group were statistically different at the pretest.

A mixed-model analysis of variance with test (pretest, posttest and follow up) as within-subject factors, and intervention (PCT, WCT, PWCT, and WPCT) as between-subject factors were performed to analyze hip strength, CPDA, running economy and lever arm length. Effect sizes for mixed ANOVAs were calculate with partial eta squatted. The significant level was set at α = 0.05. If there was a significant difference between groups, Bonferroni adjustments for multiple comparisons were used for all outcomes.

RESUILTS OF STUDY 1

Result of data analysis of the effect of part correction training, whole correction training and combination sequence on contralateral pelvic drop and running economy in long-distance recreational female runner during pretest, after 2-week training and after 4-week training.

Part 1 Participant demographics and baseline VO_2 max

Part 2 Mixed-model repeated measure ANOVA

2.1 Peak torque of hip abduction-adduction muscle (Nm/kg)

2.2 Contralateral pelvic drop angle (CPDA)

2.3 Running economy

2.4 Lever arm length

Part 1 Participant demographics and baseline VO_2 max

Table 5 Mean ± SD of participant demographics and baseline VO_2max during pretest, after 2-week training and after 4-week training.

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
VO_2max (ml/kg/min)	40.63±7.8	40.50±8.6	40.88±7.25	41.38±8.19	40.97±6.79

No overall significant difference ($p > 0.05$)

Table 5 summarizes the mean ± SD of participants demographics. The participants had average age 36.03 ± 6.27 years old, Height 159.44+4.63 centimeters, Weight 51.06±4.09 kilograms, %Body fat 25.87±2.91and baseline VO_2max 40.97±6.79 ml/kg/min.

No statistical differences were found in age, height, weight, % body fat and VO_2max among the four groups at baseline (Age: $F_{(3,28)}$ =0.062, p>0.974, η^2 = 0.008; Height: $F_{(3,28)}$ =0.133, p>0.939, η^2 = 0.54; Weight: $F_{(3,28)}$= 1.229, p>0.318, η^2 = 0.116; %Body fat: $F_{(3,28)}$ =4.732, p>0.009, η^2 = 0.336 and VO_2max: $F_{(3,24)}$=0.023, p>0.995, η^2 = 0.40). As a result, the participants in each group had similar demographical data at pretest.

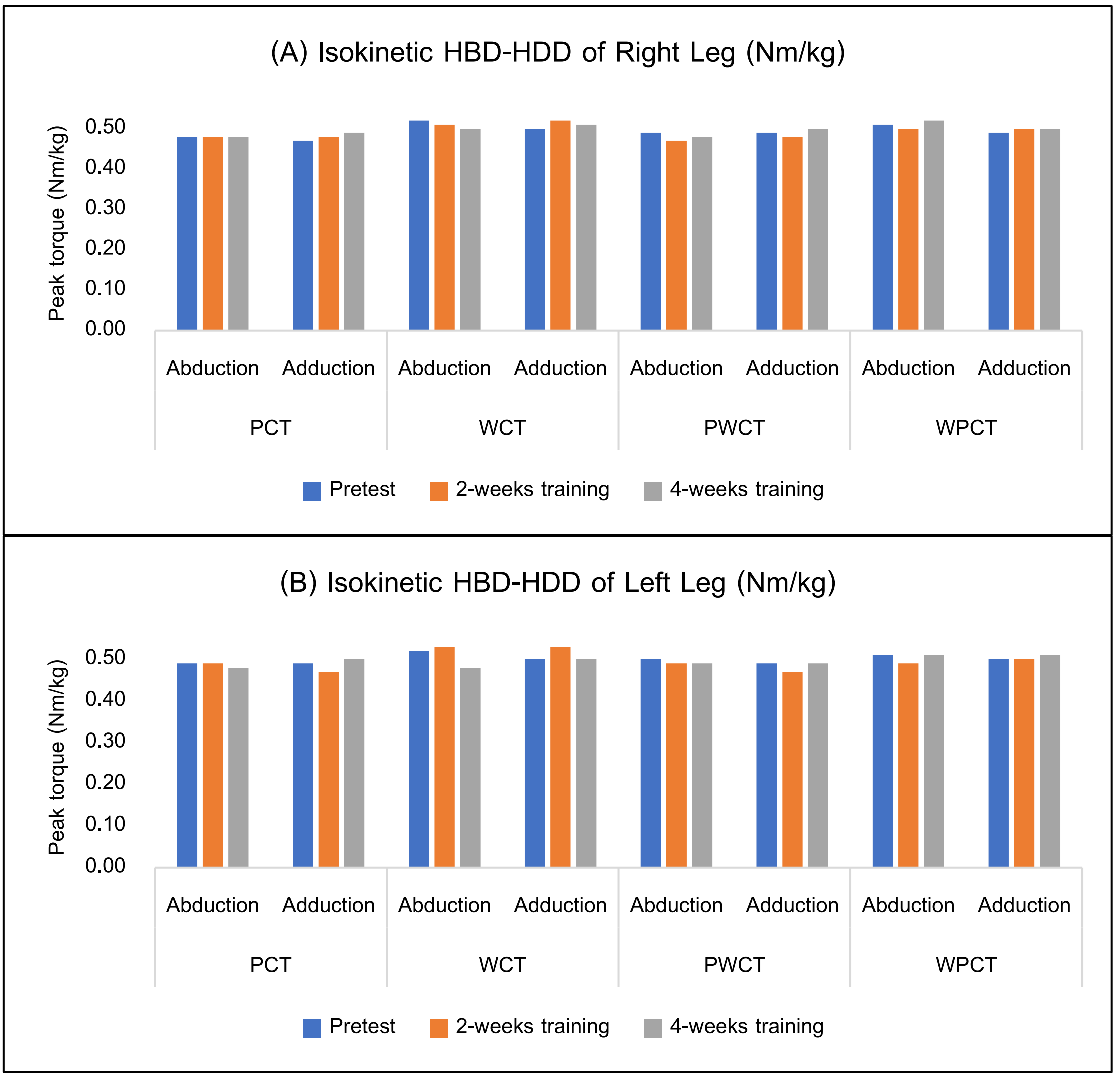
Part 2 Mixed model ANOVA of isokinetic strength test, contralateral pelvic drop angle and running economy.

2.1 Peak torque of hip abduction-adduction muscle

Table 6 Mixed model ANOVA of peak torque of hip abduction-adduction muscle during pretest, after 2-week training and after 4-week training.

Side/Action	Source of variation	df	*SS*	MS	F	Sig.	η^2
Right Abduction	Between-subject effects						
	group	3	0.021	0.007	1.069	0.379	0.103
	Error (groups)	28	0.187	0.007			
	Within- subject effects						
	Time	2	0.002	0.001	1.095	0.341	0.038
	Time x Groups	6	0.003	0.000	0.559	0.761	0.056
	Error (Time)	56	0.046	0.001			
Right Adduction	Between-subject effects						
	group	3	0.011	0.004	0.718	0.550	0.071
	Error (groups)	28	0.147	0.005			
	Within- subject effects						
	Time	2	0.002	0.001	1.125	0.332	0.039
	Time x Groups	6	0.003	0.001	0.512	0.797	0.052
	Error (Time)	56	0.059	0.001			
Left Abduction	Between-subject effects						
	group	3	0.005	0.002	0.233	0.873	0.024
	Error (groups)	28	0.215	0.008			
	Within- subject effects						
	Time	2	0.002	0.001	0.767	0.469	0.027
	Time x Groups	6	0.009	0.002	1.139	0.352	0.109
	Error (Time)	56	0.078	0.001			
Left Adduction	Between-subject effects						
	group	3	0.005	0.002	0.233	0.873	0.024
	Error (groups)	28	0.215	0.008			
	Within- subject effects						
	Time	2	0.000	0.000	0.087	0.916	0.003
	Time x Groups	6	0.011	0.002	0.918	0.489	0.090
	Error (Time)	56	0.115	0.002			

Figure 8 Peak torque of hip abduction-adduction muscle (Nm/kg) during pretest, after 2-week training and after 4-week training. (A) Right leg (B) Left leg



Mixed model analysis of variance on the isokinetic peak torque of hip abduction-adduction muscle were shown in Table 6 and Figure 8. No group x time (4x3) 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, η^2 = 0.056, Right HDD ; $F_{(6,56)}$ =0.512, p>0.797, η^2 = 0.052, Left HBD; $F_{(6,56)}$ = 1.139, p> 0.352, η^2 = 0.109 and Left HDD; $F_{(6,56)}$ =0.651, p>0689, η^2=0.065). Thus, our results showed that every training program did not statistically improve peak torque of hip.

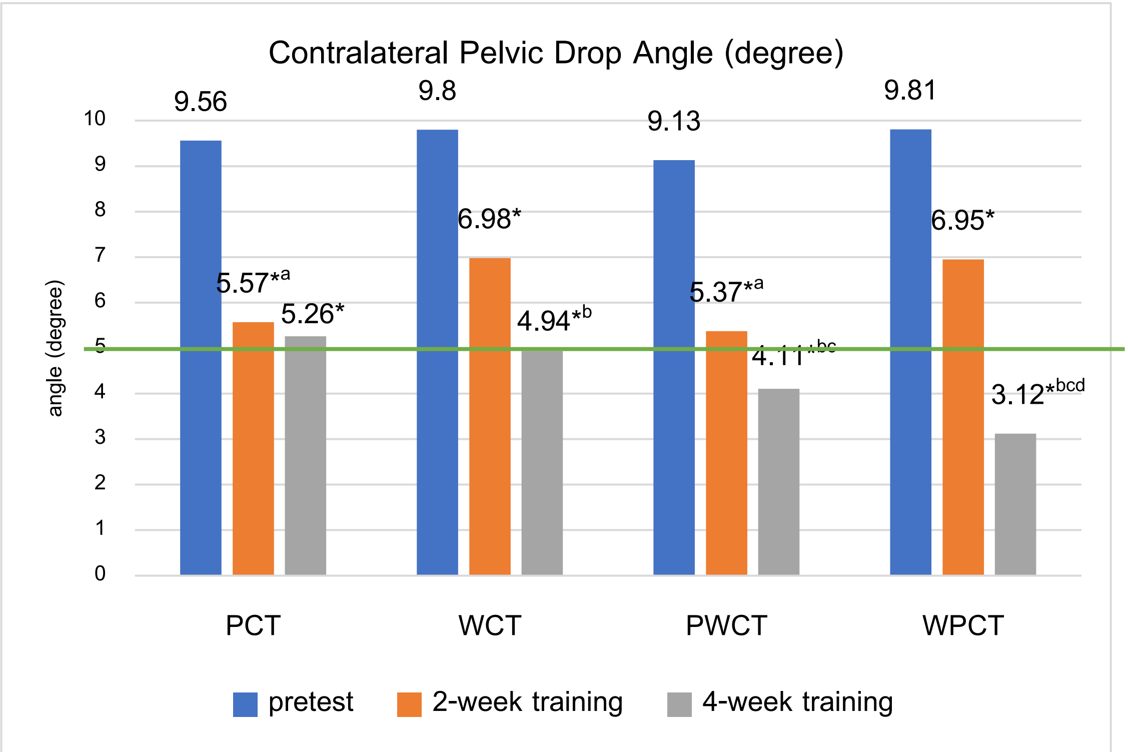
2.2 Contralateral pelvic drop angle (CPDA)

Table 7 Mixed model ANOVA of contralateral pelvic drop angle during pretest, after 2-week training and after 4-week training.

Source of variation	df	*SS*	MS	F	Sig.	η^2
Between-subject effects						
group	3	13.120	4.373	10.387	0.000*	0.527
Error (groups)	28	11.788	0.421			
Within- subject effects						
Time	2	444.241	222.121	824.154	0.000*	0.967
Time x Groups	6	29.393	4.899	18.177	0.000*	0.661
Error (Time)	56	15.093	0.270			

*Statistically significant change in mean score when compare ($p < 0.05$).

Figure 9 Mean ± SD of contralateral pelvic drop angle during pretest, after 2-week training and after 4-week training.



statistically significant change in mean score when compare ($p < 0.05$).
No statistically change in mean score when compare with posttest ($p > 0.05$).
*CPDA significantly decrease than pretest ($p < 0.05$).
[a] CPDA significantly difference when compare with WCT and WPCT ($p < 0.05$).
[b] CPDA significantly difference when compare with PCT ($p < 0.05$).
[c] CPDA significantly difference when compare with WCT ($p < 0.05$).
[d] CPDA significantly lower than PWCT ($p < 0.05$).

A mixed-model repeated measures analysis of variance on CPDA was presented in Table 7 and Figure 9, which revealed that the group x time interaction was statistically significant, $F_{(6,56)} = 18.177$, $p < 0.000$, $\eta^2 = 0.661$). Following up this interaction *indicated that* there was no significant difference between PCT, WCT, PWCT and WPCT groups at pretest *(M±SD* = 9.48 ± 0.20°, 9.79 ± 0.62°, 9.13 ± 0.67° and 9.81 ± 0.40°, respectively).

Bonferroni-adjusted comparison indicated that, PWCT (*M ±SD* = 5.37 ± 0.52°) and PCT (*M ±SD* = 5.57 ± 0.35°) reduced in CPDA greater than WPCT (*M±SD* = 6.95± 0.866°) and WCT (*M±SD* = 6.98 ± 0.96°) during after 2-weeks training.

After 4-week training, CPDA in all groups showed significant difference when compared with the pretest and after 2-week training, especially in the combined training group. WCT (*M ±SD* = 4.93 ± 0.44°) reduced in CPDA greater than PCT (*M ±SD* = 5.26 ± 0.13°). While PWCT (*M ±SD* = 4.27 ± 0.46°) reduced in CPDA greater than PCT and WCT. The WPCT *(M±SD* = 3.12 ± 0.10°*)* was the best reduction CPDA better than other groups during after 4-week training.

Furthermore, the result revealed significant difference main effect for group, $F_{(3,28)} = 10.387$, $p < 0.000$, $\eta^2 = 0.527$ and time, $F_{(2,56)} = 824.154$, $p < 0.000$, $\eta^2 = 0.967$. This effect showed that the CPDA were significantly changed over times. Bonferroni adjustments indicated that the significant main effects reflect a significant difference (p< .01) between time 1 and 2 (pretest and after 2-week training), time 1 and 3 (Pretest and after 4-week training and time 2 and 3 (after 2-week training and after 4-week training). Therefore, CPDA reduction after 2-week and 4-week training.

2.3 Running economy

Table 8 Mixed model ANOVA of running economy during pretest, after 2-week training and after 4-week training.

Source of variation	df	*SS*	MS	F	Sig.	η^2
Between-subject effects						
group	3	0.474	0.158	0.506	0.681	0.051
Error (groups)	28	8.745	0.312			
Within- subject effects						
Time	2	1.597	0.798	2.413	0.099	0.079
Time x Groups	6	3.719	0.620	1.874	0.101	0.167
Error (Time)	56	18.523	0.331			

No overall significant difference ($p > 0.05$)

Figure 10 Mean ± SD of running economy during pretest, after 2-week training and after 4-week training.

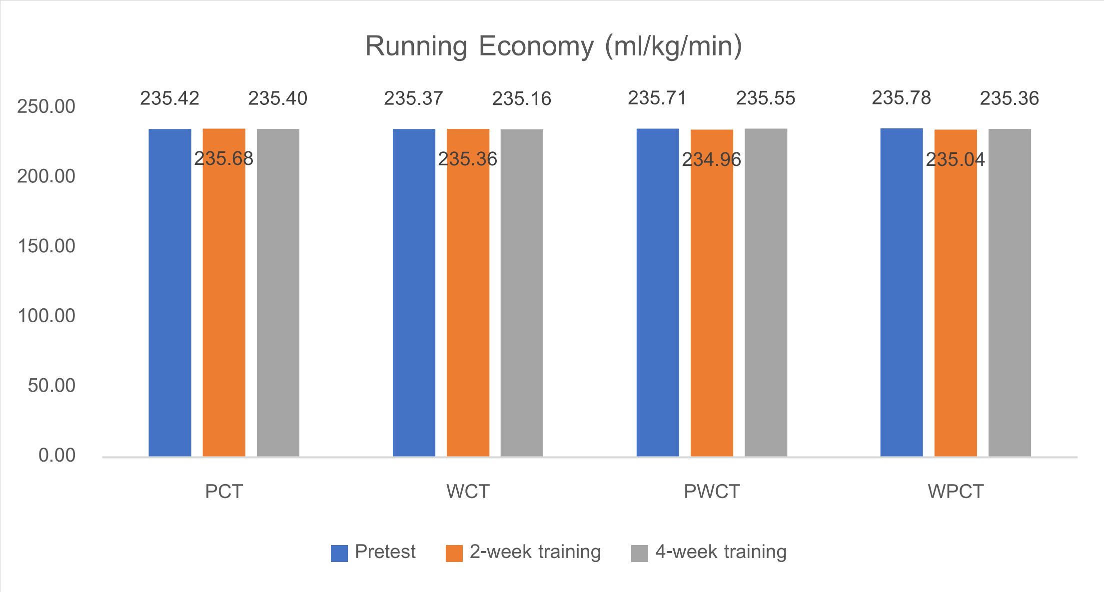


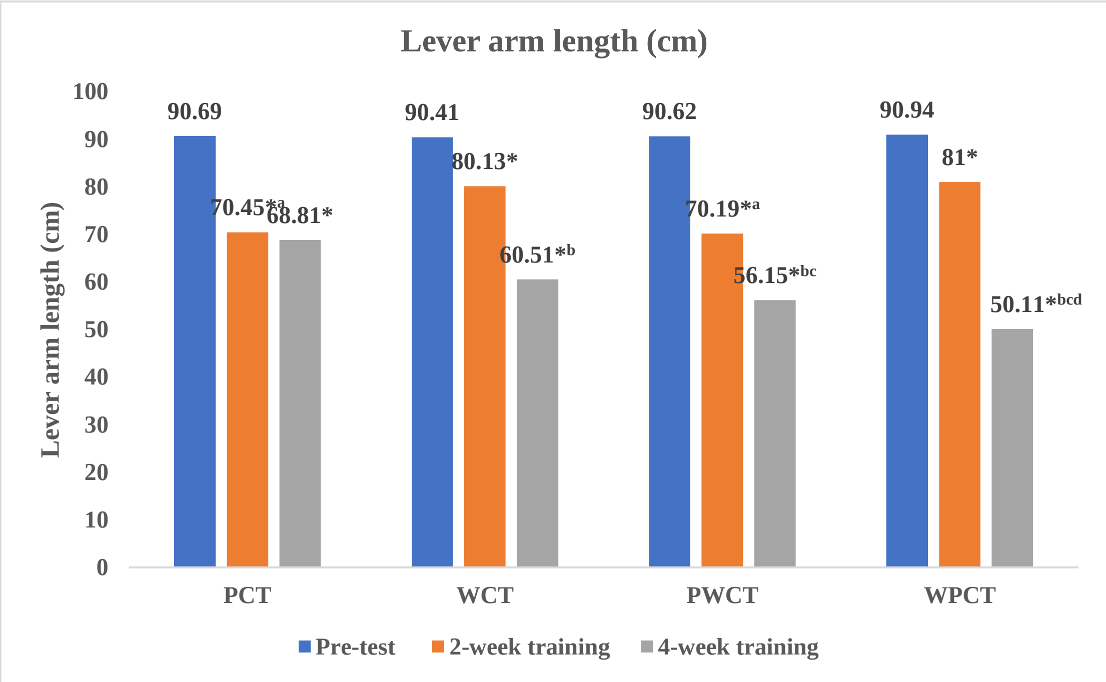
Table 8 and Figure 10 showed the running economy in pretest, after 2-week training and after 4-week training. in all experimental groups. No significant of group x time (4x3) interactions were observed for the running economy ($F_{(6,56)} = 1.874$, $p > 0.101$, $\eta^2 = 0.167$), nor were significant main effects for group, $F_{(3,28)} = 0.506$, $p > 0.681$, $\eta^2 = 0.051$ or time, $F_{(2,56)} = 2.413$, $p > 0.099$, $\eta^2 = 0.079$ present in all groups. As a result, our findings revealed that no significantly training program improved in running economy.

Table 9 Mixed model ANOVA of lever arm length during pretest, after 2-week training and after 4-week training.

Source of variation	df	*SS*	MS	F	Sig.	η^2
Between-subject effects						
group	3	358.481	119.494	245.607	0.000*	0.963
Error (groups)	28	13.623	0.487			
Within-subject effects						
Time	2	1615.865	807.933	896.274	0.000*	0.997
Time x Groups	6	1970.986	328.498	364.537	0.000*	0.957
Error (Time)	56	50.464	0.901			

*Statistically significant change in mean score when compare (p< 0.05).

Figure 11 Mean ± SD of lever arm length during the pretest, after 2-week training and after 4-week training.



statistically significant change in mean score when compare ($p< 0.05$).
No statistically change in mean score when compare with posttest ($p> 0.05$).
*Lever arm length significantly decrease than pretest ($p< 0.05$).
[a]Lever arm length significantly difference when compare with WCT and WPCT ($p< 0.05$).
[b] Lever arm length significantly difference when compare with PCT ($p< 0.05$).
[c] Lever arm length significantly difference when compare with WCT ($p< 0.05$).
[d] Lever arm length significantly lower than PWCT ($p< 0.05$).

A mixed-model repeated measures analysis of variance on CPDA was presented in Table 9 and Figure 11, which revealed that the group x time interaction was statistically significant, $F_{(6,56)} = 364.537$, $p< 0.000$, $\eta^2 = 0.975$). *Following up on this interaction indicated that* there was no significant difference between PCT, WCT, PWCT, and WPCT groups at the pretest *(M±SD* = 90.69 ± 0.91, 90.41 ± 1.48, 90.62 ± 0.61, and 90.62 ± 1.17 centimeter, respectively).

Bonferroni-adjusted comparison indicated that, PWCT (*M ±SD* = 70.19 ± 0.71) and PCT (*M ±SD* = 70.45 ± 0.0.65°) reduced in lever arm length greater than WCT (*M±SD* = 80.13 ± 0.86) and WPCT (*M±SD* = 81.00 ± 1.21) during after 2-weeks training.

After 4-week training, lever arm length in all groups showed a significant difference when compared with the pretest and after 2-week training, especially in the combined training group. WCT (*M ±SD* = 60.51± 0.54) reduced in lever arm length greater than PCT (*M ±SD* = 68.81 ±0.70). While PWCT (*M ±SD* = 56.20 ± 1.04) was reduced in lever arm length greater than PCT and WCT. The WPCT *(M±SD* = 50.11± 0.60*)* was the best significant reduction in the lever arm length better than other groups after 4-week training.

The result revealed significant difference main effect for group, $F_{(3,28)} = 245.607$, $p < 0.000$, $\eta^2 = 0.963$ and time, $F_{(2,56)} = 896.274$, $p < 0.000$, $\eta^2 = 0.997$. This effect showed that the lever arm length was significantly changed over time. Bonferroni adjustments indicated that the significant main effects reflect a significant difference (p< .01) between time 1 and 2 (pretest and after 2-week training), time 1 and 3 (Pretest and after 4-week training and time 2 and 3 (after 2-week training and after 4-week training). Therefore, lever arm length reduction after 2-week and 4-week training.

DISCUSSION OF STUDY 1

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 goal was to compare the benefits among a combined correction training (PWCT and WPCT) and a single correction training (PCT and WCT). It was hypothesized that a combined correction training was able to better improve reduction of CPDA and lever arm length because it consolidated benefits from both part correction training and whole correction training.

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 the benefits of both part correction training and whole correction training. In PCT, the participants had substantially reduced their attention demand in fixing errors by focusing only a specific task. While there were many variables in WCT, WCT were benefited from an appreciation of spatial and temporal coordination during movements (Magill & Anderson, 2010). Practicing only PCT maybe beneficial in the acquisition of skills, but the participants may struggle later when they combined all partial acquired skills to create the whole movements. For the participants who performed only WCT, it was possible that the information was overloaded, and the participants were not able to successfully address their errors ((Kalyuga, 2011; Wickens, Hutchins, Carolan, & Cumming, 2013). Moreover, combining the two training programs encouraged both motor acquisition and motor adaptation which involved in learning a new movement pattern (Caramiaux, Françoise, Liu, Sanchez, & Bevilacqua, 2020; Magill & Anderson, 2010; Rhein & Vakil, 2018).

Our finding highlighted the importance of the order in correction training. The finding showed CPDA and lever arm length in WPCT was statistically better than CPDA in PWCT. In WPCT, the participants began their correction training by receiving feedbacks during running for two weeks before performing SSLS for another two weeks. Since running is a movement activity that the participants normally experienced, receiving feedbacks from whole practice (or running) encouraged new cognitive framing and adjusting motor skills to address CPD (Agresta & Brown, 2015; Davis & Futrell, 2016; Leech, Roemmich, Gordon, Reisman, & Cherry-Allen, 2022). As the audio feedbacks faded, the participants needed to use the instant visual feedbacks and the new cognitive framing received from audio feedbacks to create their own motor strategy to coordinate their muscle movements at the right time to reduce CPD (Leech et al., 2022; Spampinato & Celnik, 2021). After the participants were familiar with their own motor strategy, SSLS specifically focused on existed residual technical errors to help further improve of CPD. The participants received specific feedbacks during SSLS resulting in sensorimotor adaptation and in promoting muscle synergy. SSLS trained the gluteus medius to act as the synergy of hip muscles during stance leg. Moreover, the training allowed hip muscles to coactivate to maintain hip level and regulate the pelvic movement in frontal plane (D'Avella, Saltiel, & Bizzi, 2003; Hagio & Kouzaki, 2014; Mehrabi, Schwartz, & Steele, 2019).

In order 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 such as muscular recruitment, synchronization, adaptations of synergist muscles and/or activation that benefit the CPD. However, employing electromyography is recommended in order to understand muscle adaptations in the training.

While it has been demonstrated that running biomechanics influence RE, there is limited evidence that biomechanical adjustment can improve RE. The current study showed a similar outcome that there was no significant difference in running economy after 4-weeks training within-group and between-group, whereas the CPDA decreased significantly. There is minimal evidence to support the implementation of a muscular reeducation strategy in improving the running economy from currently available literature (Clansey, Hanlon, Wallace, Nevill, & Lake, 2014; Craighead, Lehecka, & King, 2014; Dallam, Wilber, Jadelis, Fletcher, & Romanov, 2005; Moran & Wager, 2020). It is possible that the training period in the study was too short to have an impact on running economy.

The outcome of this study showed positive result in altering CPD during running with combined whole-part correction technique which include SSLS training and actual running along with real-time feedback. Therefore, participants were able to perform each movement more accurately. However, this study had potential limitations which were lack of previous research studies on the topic and lack of a control group in the study that limit the ability to quantify the change solely brought about the training.

CHAPTER 4
STUDY 2
RETENTION

This study was examined the retention effects of every method; part correction training, whole correction training, a combined part-whole correction training and a combined whole-part correction training were to be studies which method was the most effective in the shortest period on contralateral pelvic drop and running economy in long-distance recreational female runners.

PARTICIPANTS

The participants in study 2 were the same group as study 1. In the reason that it was a continuous process whereas study 2 would examine the retention effects from the training program in study 1. The duration and procedure the process would be inform to participants beforehand that they would have to participate for 6 times.

PROCEDURE

After the 4-week training program completed, all participants were reassessed for 1 month. The testing procedure was identical to the initial assessment – the contralateral pelvic drop angle, running economy, isokinetic strength test and lever arm length for 1 month. The follow up procedure would be done on the 1st, 2nd and 4th week, participants would be asked to report their weekly distance, other training program included.

1. Retention 1 (1st-week follow up)

When all participants of every group completed the 4-week training program, they were given time to recover for 1 week then had to re-test with the same procedure of collecting initial assessment data of the experiment, the contralateral pelvic drop angle during the midstance of stance phase, isokinetic strength testing of hip muscle and running economy. These testing procedures were collected at the same location, with researcher and research assistant who was a sports science officer closely supervised throughout the test. The procedures of the test were as follow item 5 in study 1.

2. Retention 2 (2nd-week follow up)

After all participants completed the 4-week training program and the first retention on the following week, they were given time to recover for another 1 week then had to re-test on the 2nd week post-training with the same procedure of collecting initial assessment data of the experiment, the contralateral pelvic drop angle during the midstance of stance phase, isokinetic strength testing of hip muscle and running economy. These testing procedures were collected at the same location, with researcher and research assistant who was a sports science officer closely supervised throughout the test. The procedures of the test were as follow.

3. Retention 3 (4th-week follow up)

After all participants completed the 4-week training program and the second retention on the following week, they were given time to recover for another 2 weeks then had to re-test on the 4th week post-training with the same procedure of collecting initial assessment data of the experiment the contralateral pelvic drop angle during the midstance of stance phase, isokinetic strength testing of hip muscle and running economy. These testing procedures were collected at the same location, with researcher and research assistant who was a sports science officer closely supervised throughout the test. The procedures of the test were as follow.

4. Statistical Analysis

5. Discussion and Conclusion

EQUIPMENT OF STUDY 2

1. Equipment of evaluation of contralateral pelvic drop angle and lever arm length

1.1 Motion analysis system Qualisys Track Manager (QTM 2.15 build 3300)

1.2 Performance module Visual 3D 6.0.0., C-Motion Inc., Rockville, MD, USA

1.3 Qualisys PAF running package marker set, Sweden (Appendix B)

1.4 Camera motion capture system Oqus7+, Qualisys AB, Sweden

2. Equipment of evaluation of Isokinetic strength test

2.1 Biodex System 4 Dynamometer, Shirley, NY, USA

3. Equipment of evaluation of running economy

3.1 Bioelectrical Impedance Analyzer, Jawon (OI 353 whole body,), Korea

3.2 Heart rate monitor, Polar (FT40), Finland

3.3 Breath by Breath Cardiopulmonary gas exchange system, Cortex (Metamax 3BR2 system), Germany

4.4 HP Cosmos treadmill, Pluto version, Germany

5. Equipment of training session (Appendix F)

5.1 Sprintex Natural Movement treadmill, USA

5.2 52 inches Samsung LED monitor, Korea

5.3 32 inches Dell LED monitor,

5.4 Running Analysis System, Kinovea program, Frenc

STATISTICAL ANALYSIS

Statistical Package for Social Sciences (version 23; IBM, Armonk, NY, USA) was used to conduct all statistical analyses. A Shapiro-Wilk test was performed to determine if the data were normally distributed. Group demographics were compared using one-way analyses of variance (ANOVA) test in order to check if the demographics of each group were statistically different at the pretest.

A mixed-model analysis of variance with test (pretest, 1st,2nd and 4th-follow up) as within-subject factors, and intervention (PCT, WCT, PWCT, and WPCT) as between-subject factors were performed to analyze hip strength, CPDA, running economy and lever arm length. Effect sizes for mixed ANOVAs were calculate with partial eta squatted. The significant 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.

RESUILTS OF STUDY 2

Result of data analysis of the retention of part correction training, whole correction training and combination sequence on contralateral pelvic drop and running economy in long-distance recreational female runner during after 4-week training, 1-week follow up, 2-week follow up and 4-week follow up.

Part 1 Participant demographics

Part 2 Mixed model repeated measure ANOVA

2.1 Peak torque of hip abduction-adduction muscle

2.2 Contralateral pelvic drop angle (CPDA)

2.3 Running economy

2.4 Lever arm length

Part 1 Participant demographics

Table 10 Mean ± SD of participant demographics after 4-week training, 1-week follow up, 2-week follow up and 4-week follow up.

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±7.11	36.03 ± 6.27
Height	159.62±4.63	159.38±4.60	160.19±3.59	158.63±6.39	159.44+4.63
Weight(kg)	51.91±4.14	50.08±2.40	51.64±3.50	51.05±5.02	51.17±4.11
%Body fat	25.73±1.96	26.13±3.39	25.96±2.41	25.64±2.84	25.87±2.93

No overall significant difference ($p > 0.05$)

Table 9 summarizes the mean ± SD of participants demographics. The participants had average age 36.03 ± 6.27 years old, Height 159.44+4.63 centimeters, Weight 51.17±4.11 kilograms, %Body fat 25.87±2.93.

No statistical differences were found in age, height, weight, % body fat and VO_2max among the four groups at baseline (Age: $F_{(9,84)}$ =0.062, p>0.979, η^2 = 0.007; Height: $F_{(9,84)}$ =0.133, p>0.939, η^2 = 0.14; Weight: $F_{(9,84)}$= 0.838, p>0.485, η^2 = 0.082; %Body fat: $F_{(9.84)}$ =2.223, p>0.082, η^2 = 0.192. As a result, the participants in each group had similar demographical data at after 4-week training.

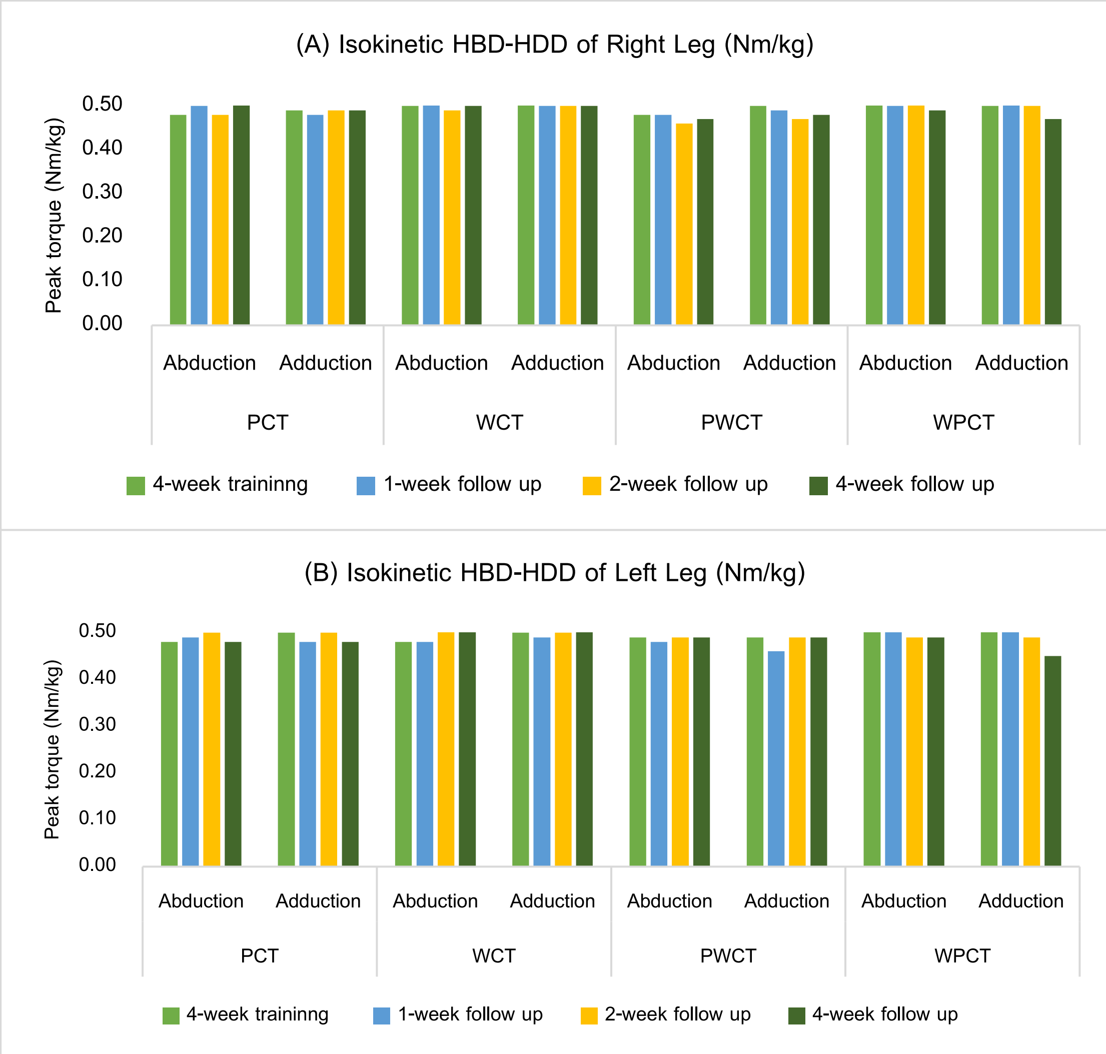
Part 2 Mixed model ANOVA of isokinetic strength test, contralateral pelvic drop angle and running economy.

2.1 Peak torque of hip abduction-adduction muscle

Table 11 Mixed model ANOVA of peak torque of hip abduction-adduction muscle after 4-week training, 1-week follow up, 2-week follow up and 4-week follow up.

Side/Action	Source of variation	df	*SS*	MS	F	Sig.	η^2
Right Abduction	Between-subject effects						
	group	3	0.016	0.005	0.748	0.533	0.074
	Error (groups)	28	0.198	0.007			
	Within- subject effects						
	Time	3	0.001	0.000	0.275	0.843	0.010
	Time x Groups	9	0.009	0.001	1.133	0.349	0.108
	Error (Time)	84	0.077	0.001			
Right Adduction	Between-subject effects						
	group	3	0.004	0.001	0.226	0.878	0.024
	Error (groups)	28	0.178	0.006			
	Within- subject effects						
	Time	3	0.006	0.002	1.862	0.142	0.062
	Time x Groups	9	0.006	0.001	0.537	0.843	0.054
	Error (Time)	84	0.096	0.001			
Left Abduction	Between-subject effects						
	group	3	0.003	0.001	0.103	0.957	0.011
	Error (groups)	28	0.257	0.009			
	Within- subject effects						
	Time	3	0.001	0.000	0.074	0.974	0.003
	Time x Groups	9	0.015	0.002	0.657	0.745	0.066
	Error (Time)	84	0.206	0.002			
Left Adduction	Between-subject effects						
	group	3	0.009	0.003	0.329	0.804	0.034
	Error (groups)	28	0.267	0.010			
	Within- subject effects						
	Time	3	0.007	0.002	0.931	0.430	0.032
	Time x Groups	9	0.024	0.003	1.159	0.332	0.110
	Error (Time)	84	0.196	0.002			

Figure 12 Peak torque of hip abduction-adduction muscle after 4-week training, 1-week follow up, 2-week follow up and 4-week follow up. (A) Right leg (B) Left leg



Mixed model analysis of variance on the isokinetic peak torque of hip abduction-adduction muscle were shown in Table 10 and Figure 10. No group x time (4x4) 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; $F_{(9,84)} = 1.133$, $p>0.349$, $\eta^2 = 0.054$, *Right HDD*; $F_{(9,84)} = 0.537$, $p>0.943$, $\eta^2 = 0.054$, *Left HBD*; $F_{(9,84)} = 0.657$, $p> 0.745$, $\eta^2 = 0.066$ *and Left HDD*; $F_{(9,84)} = 1.159$, $p>0.332$, $\eta^2=0.110$). *Thus, our results showed that hip abduction-adduction muscle in every training program did not statistically change overtime when compared after 4-week training.*

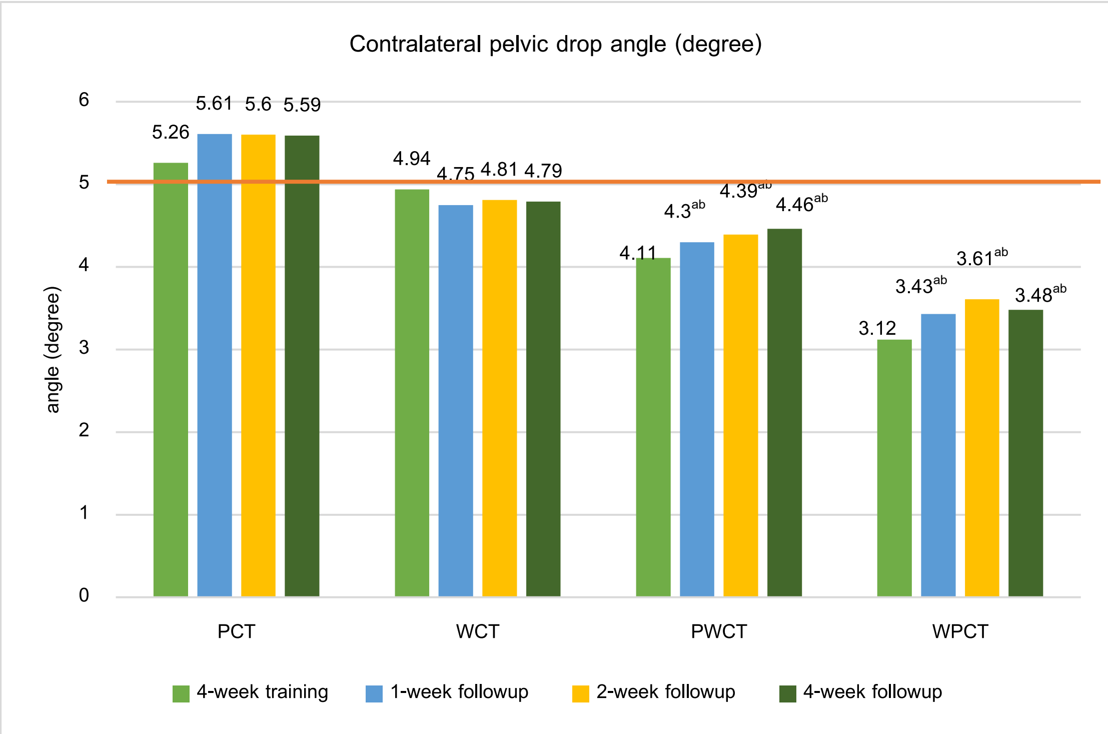
2.2 Contralateral pelvic drop angle (CPDA)

Table 12 Mixed model ANOVA of contralateral pelvic drop angle after 4-week training, 1-week follow up, 2-week follow up and 4-week follow up.

Source of variation	df	SS	MS	F	Sig.	η^2
Between-subject effects						
group	3	75.744	25.248	33.327	0.000*	0.781
Error (groups)	28	21.212	0.758			
Within- subject effects						
Time	3	1.211	0.404	3.567	0.071	0.113
Time x Groups	9	1.255	0.139	1.233	0.286	0.117
Error (Time)	84	9.504	0.113			

*Statistically significant change in mean score when compare with after 4-week training ($p < 0.05$).

Figure 13 Mean ± SD of contralateral pelvic drop angle after 4-week training, 1-week follow up, 2-week follow up and 4-week follow.



No statistically change in mean score when compare with 4-week training ($p > 0.05$).
*CPDA significantly decrease than pretest ($p < 0.05$).
[a] CPDA significantly difference when compare with WCT
[b] CPDA significantly difference when compare with PCT ($p < 0.05$).

A mixed-model ANOVA on CPDA was presented in Table 7 and Figure 11, which revealed that the group x time interaction was not statistically significant, $F_{(9,84)} = 1.233$, $p < 0.286$, $\eta^2 = 0.117$). This interaction indicated that CPDA in all groups was not significant difference when compared with the after 4-week training that shows the retention of learning was active during 1-month without training.

However, the result revealed significant difference main effect for group, $F_{(3,28)} = 33.327$, $p < 0.000$, $\eta^2 = 0.781$ but not significant difference in time, $F_{(3,84)} = 3.567$, $p < 0.071$, $\eta^2 = 0.113$. This effect showed that the CPDA were not significantly changed over times.

Bonferroni-adjusted comparison indicated that, WPCT (*M ±SD* = 3.34 ± 0.33°) and PWCT (*M ±SD* = 4.30 ± 0.80°) remined reduction in CPDA greater than WCT (*M ±SD* = 4.75 ± 0.64°) and PCT (*M ±SD* = 5.61 ± 0.70°) during after 1-week follow up.

After 2-week follow up, WPCT (*M ±SD* = 3.61 ± 0.16°) remained reduction in CPDA greater than PWCT (*M±SD* = 4.39 ± 0.78°), WCT (*M±SD* = 4.81 ± 0.59°) and PCT (*M±SD* = 5.60 ± 0.47°). Moreover, the *WPCT* (*M ±SD* = 3.48 ± 0.028°) was the best retention better than PWCT (*M ±SD* = 4.46 ± 0.39°), WCT (*M ±SD* = 4.78 ± 0.53°) and PCT (*M ±SD* = 5.59 ± 0.55°) during 4-week follow up. Therefore, WPCT performed the best retention of skill after 4-week training.

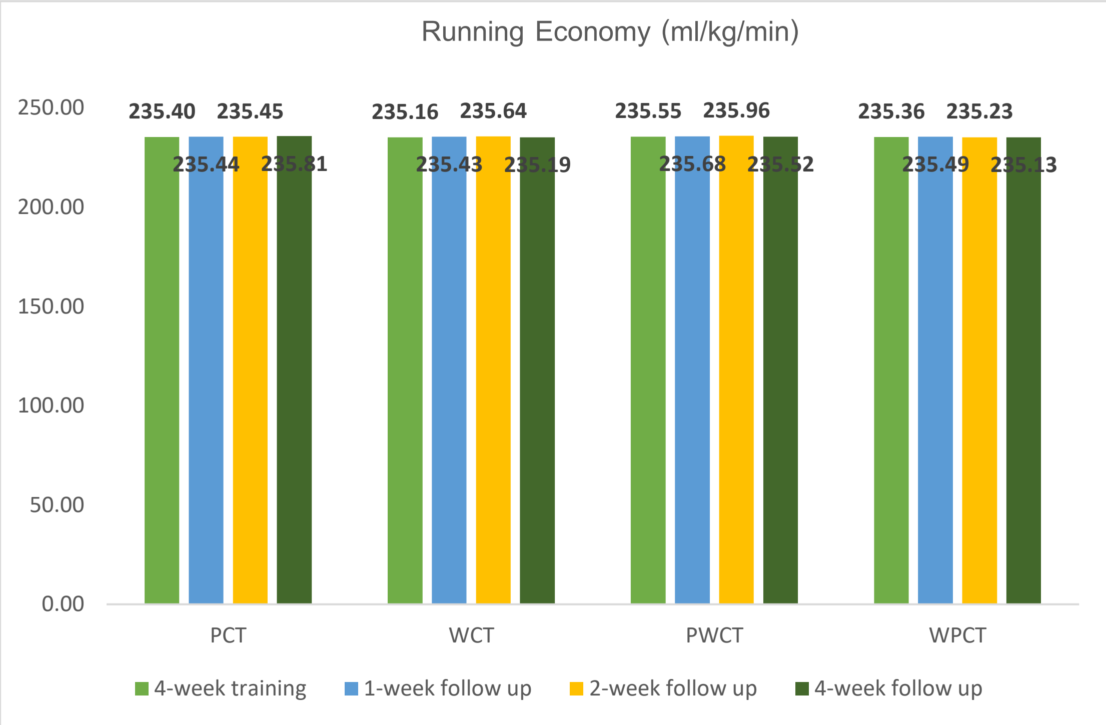
2.3 Running economy

Table 13 Mixed model ANOVA of running economy after 4-week training, 1-week follow up, 2-week follow up and 4-week follow up.

Source of variation	df	*SS*	MS	F	Sig.	η^2
Between-subject effects						
group	3	2.799	0.933	0.039	0.989	0.04
Error (groups)	28	663.930	23.712			
Within- subject effects						
Time	3	0.792	0.264	0.11	0.998	0.000
Time x Groups	9	2.857	0.317	0.13	1.000	0.001
Error (Time)	84	2081.935	24.785			

No overall significant difference (p > 0.05)

Figure 14 Mean ± SD of running economy after 4-week training, 1-week follow up, 2-week follow up and 4-week follow up.



No overall significant difference ($p > 0.05$)

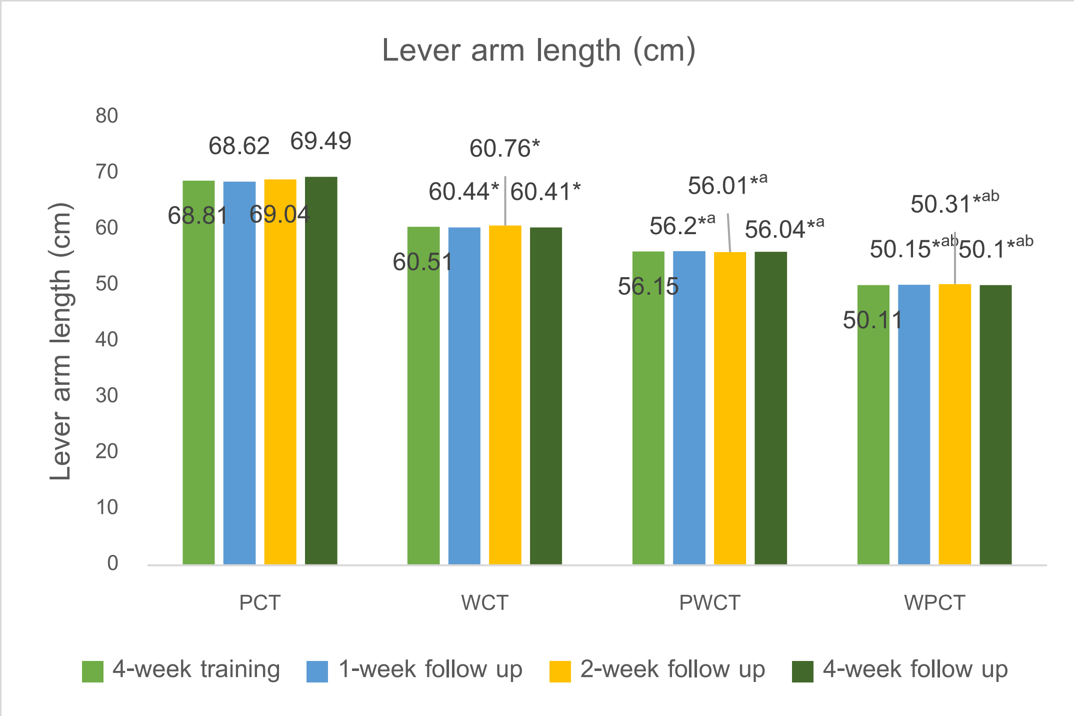
Table 12 and Figure 12 show the running economy after 4-week training, 1-week follow up, 2-week follow up and 4-week follow up in all experimental groups. No significant of group x time (4x4) interactions were observed for the running economy ($F_{(9,84)} = 0.130$, $p > 1.000$, $\eta^2 = 0.001$), nor were significant main effects for group, $F_{(3,28)} = 0.039$, $p > 0.989$, $\eta^2 = 0.040$ or time, $F_{(3,84)} = 0.11$, $p > 1.000$, $\eta^2 = 0.001$, present in all groups. As a result, our findings revealed that no significantly training program improved in running economy.

Table 14 Mixed model ANOVA of lever arm length after 4-week training, 1-week follow up, 2-week follow up, and 4-week follow up.

Source of variation	df	SS	MS	F	Sig.	η^2
Between-subject effects						
group	3	603.821	201.274	356.348	0.000*	0.997
Error (groups)	28	15.790	0.564			
Within-subject effects						
Time	3	0.731	0.244	0.994	0.400	0.034
Time x Groups	9	3.749	0.417	1.699	0.102	0.154
Error (Time)	84	20.591	0.245			

*Statistically significant change in mean score when compare with after 4-week training ($p < 0.05$).

Figure 15 Mean ± SD of lever arm length angle after 4-week training, 1-week follow up, 2-week follow up and 4-week follow.



No statistical change in the mean score when compared with 4-week training (p> 0.05).

[*] Lever arm length significantly different when compare with PCT (p< 0.05).

[a] Lever arm length significantly different when compare with WCT (p< 0.05).

[b] Lever arm length significantly different when compare with PWCT (p< 0.05).

A mixed-model ANOVA on lever arm length was presented in Table 14 and Figure 15, which revealed that the group x time interaction was not statistically significant, $F_{(9,84)}$ =1.699, p< 0.102, η^2= *0.154).* This interaction indicated that lever arm length in all groups was not a significant difference when compared with the after 4-week training which demonstrates the retention of learning was active during the 1-month without training.

However, the result revealed significant difference main effect for group, $F_{(3,28)}$ *=356.348, p < 0.000,* η^2= 0.997 but not significant difference in time, $F_{(3,84)}$ = *0.994*, p< 4.000, η^2= 0.034. This effect showed that the lever arm length was not significantly changed over times.

Bonferroni-adjusted comparison indicated that, WPCT (*M ±SD* = 50.15 ± 0.51) was the best for retention skill greater than the WPCT (*M ±SD* = 56.20 ±1.04), WCT (*M ±SD* = 60.44 ±0.54) and PCT (*M ±SD* = 68.62 ±0.34), respectively during 1-week follow up.

After 2-week follow up, WPCT (*M ±SD* = 50.31 ± 0.35) remained reduction in lever arm length greater than PWCT (*M±SD* = 56.01 ± 0.58°), WCT (*M±SD* = 60.76± 0.4°) and PCT (*M±SD* = 60.04± 0.59), respectively. *Furthermore, the* WPCT *(M ±SD = 50.10 ± 0.60)* was the best retention better than PWCT *(M ±SD = 56.04 ± 0.43), WCT (M ±SD* =60.41 ± 0.54) and PCT *(M ±SD* = 69.49 ± 0.58°) during 4-week follow up. Therefore, WPCT performed the best retention of skill after 4-week training.

DISCUSSION OF STUDY 2

The purpose of this study was to compare the retention of 4-week neuromuscular training programs (PCT, WCT, PWCT and WPCT) on CPDA during midstance of female runners. Our purpose was to examine a correction training (PWCT and WPCT) compared to a single correction training (PCT and WCT). It was postulated the combined correction training could was able to better retention of the skill than single correction training.

During retention test period (1^{st}, 2^{nd} and 4^{th} week follow up), we found no statistical differences in CPDA within-group of all groups. The results indicated that the participants in all groups were able to modify motor behavior and retain their improved skills after 1-month training. In line with Willy and Davis (2011) investigated the learning to reduce hip adduction angles during running used a single-leg squat as retention test. They found that significant reduced hip adduction and reported similar reductions that were maintained beyond 1-month post training. Our results conformed with several studies whose results showed that participants made fewer movement mistakes and relearned new movements after neuromuscular training with motor learning approach (Helm, Pohlig, Kumar, & Reisman, 2019; Leech et al., 2022).

Due to the activation of the Mirror Neuron System by the real-time visual video feedback which transmitted information about how to perform a motor skill. Dynamic of visualizations exerts less strain on participants' working memory resources than presenting materials that do not involve human movement (Rizzolatti & Craighero, 2004). In addition, it reduced the cognitive load of participants, which better engage process of selecting, organizing, and integrating the new movement pattern including enhanced long-term learning (H'mida et al., 2022).

Our results also 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. CPDA after 1-month follow up was not statistically different from that of post trainin

CHAPTER 5

DISCUSSION AND CONCLUSION

DISCUSSION

The goal of this study is to compare the effects of 4-week neuromuscular training programs (PCT, WCT, PWCT and WPCT) and to describe the retention of those programs on CPDA and running economy during midstance in recreational female runners.

During the first 2 weeks, neuromuscular training program using the part correction training, addressing only one dependent movement along with verbal and visual feedback, is more effective in lowering the CPDA than whole correction training. As a result, when the provided instruction is simple and precise, it is easier to understand and manage.

The result of a 4-week of shows that PWCT and WPCT was the most effective program to help reducing CPDA. WCT also showed some reducing CPDA. However, PCT showed no significant improvement. 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 the benefits of both part correction training and whole correction training. Our finding highlighted the importance of the order in correction training. The finding showed CPDA in WPCT was statistically better than CPDA in PWCT. In WPCT, the participants began their correction training by receiving feedbacks during running for two weeks before performing SSLS for another two weeks. Since running is a movement activity that the participants normally experienced, receiving feedbacks from whole practice (or running) encouraged new cognitive framing and adjusting motor skills to address CPD (Agresta & Brown, 2015; Davis & Futrell, 2016; Leech et al., 2022). As the audio feedbacks faded, the participants needed to use the instant visual feedbacks and the new cognitive framing received from audio feedbacks to create their own motor strategy to coordinate their muscle movements at the right time to reduce CPD (Leech et al., 2022; Spampinato & Celnik, 2021). After the participants were familiar with their own motor strategy, SSLS specifically focused on existed residual technical errors to help further improve of CPD.

The participants received specific feedbacks during SSLS resulting in sensorimotor adaptation and in promoting muscle synergy. SSLS trained the gluteus medius to act as the synergy of hip muscles during stance leg. Moreover, the training allowed hip muscles to coactivate to maintain hip level and regulate the pelvic movement in frontal plane (D'Avella et al., 2003; Hagio & Kouzaki, 2014; Mehrabi et al., 2019).

In order 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 such as muscular recruitment, synchronization, adaptations of synergist muscles and/or activation that benefit the CPD. However, employing electromyography is recommended in order to understand muscle adaptations in the training.

While it has been demonstrated that running biomechanics influence RE, there is limited evidence that biomechanical adjustment can improve RE. The current study showed a similar outcome that there was no significant difference in running economy after 4-weeks training within-group and between-group, whereas the CPDA decreased significantly. There is minimal evidence to support the implementation of a muscular reeducation strategy in improving the running economy from currently available literature (Clansey et al., 2014; Craighead et al., 2014; Dallam et al., 2005; Moran & Wager, 2020). It is possible that the training period in the study was too short to have an impact on running economy.

During retention test period (1st, 2nd and 4th week follow up), we found no statistical differences in CPDA within-group of all groups. The results indicated that the participants in all groups were able to modify motor behavior and retain their improved skills after 1-month training. In general, improving the volume of training via task repetition can improve the retention of skill. WPCT were trained by running before SSLS. When performed running, an improvement within motor behavior relies on the feedback about failure or success of the movement relative to a task. The faded feedback encourages the participants to experience with vary motions and choose actions that have the best chance to succeed while avoid action that cannot succeed. It is believed that the basal ganglia and primary motor cortex coordinate with the basal ganglia-thalamo-cortical circuits (Uehara, Mawase, & Celnik, 2018). This might be facilitated through reward-based dopamine signaling in which dopaminergic neuron activity increased to response when the tasks are success. When performing SSLS, it encourages sensorimotor adaptation by adding more procedures that require practicing of unfamiliar task. Study have found that it helps improve retention (Leech et al., 2022). This would lead to automatic process that bias the future movement selection to correctly apply with actual running skill.

Our findings also demonstrated the value of deliberate practice, in which participants optimized their movement approach to correct movement errors and then memorized the relearned motions to rectify the errors. After a one-month follow-up, the CPDA was statistically indistinguishable from the pre-training level.

Limitations of this study should be considered. The neuromuscular training program is only available in a biomechanics laboratory, which is not suitable for most runners. Because the contralateral pelvic drop is an impalpable biomechanical metric. In the futures study should consider the possibility of using wearable sensor technologies to quantify CPDA and running economy in outdoor setting.

PRACTICAL IMPRICATION

As it is shown in our resul, the whole-part correctiong training is the best method to practically apply for real world training. It will be most suitable for correcting the biomechanics of movements with high organization and low complexity such as running, walking, cycling or swimming. Not only movements in sports but also in everyday life as well. The whole followed by pat correction training can also correct ergonomic for people who work with a repititive motion all day. It can also be adapted for rehabilitaion after a surgery to restore function or reach hight level of capanility.

CONCLUSION

The study investigated the effects of 4-weeks neuromuscular training programs on contralateral pelvic drop (CPD) and running economy (RE) in female runners. Thirty-two female runners who experienced CPD volunteered for the study. The participants were divided into 4 groups of eight participants. The first two groups performed single correction trainings where the first group performed PCT, while the second group performed WCT. The third and fourth group performed PWCT and WPCT, respectively. The participants were assessed for contralateral pelvic drop angle (CPDA) and running economy (RE). CPDA was assessed during stance phase using 3D motion analysis, while RE was assessed using incremental running test. The results showed that the group x time interaction was statistically significant in CPDA, while no statistical differences were found among four groups in RE. Further analysis suggested that WPCT was the most effective program in addressing CPDA. The study findings suggested that the whole-part correction training was most appropriate for correcting CPDA within a short period. 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 where CPDA after 1-month follow up marginally differed from that of post training.

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APPENDIX

APPENDIX A

APPENDIX A
แบบสอบถามที่ใช้ในการวิจัย

เลขที่……………….

วันที่ทำการเก็บข้อมล………/…………../…………

คำแนะนำในการตอบแบบสอบถาม

1. แบบสอบถามประกอบด้วย 3 ส่วน

ส่วนที่ 1 ข้อมูลส่วนบุคคล

ส่วนที่ 2 ข้อมูลเกี่ยวกับการวิ่ง

ส่วนที่ 3 ข้อมูลเกี่ยวกับการบาดเจ็บ

2. ให้ทำการตอบแบบสอบถามให้ครบทุกข้อ เพื่อให้แบบสอบถามสมบูรณ์ และสามารถนำผลมาวิเคราะห์ได้

ส่วนที่ 1 ข้อมูลส่วนบุคคล

1. อายุ……………ปี
2. น้ำหนัก ……………………………..
   ส่วนสูง……………………………...
3. ความแตกต่างของความยาวขาทั้ง 2 ข้าง (Leg length discrepancy)

True leg length (ASIS – Medial malleoli)

- ขาขวา (Right) …………………เซนติเมตร
- ขาซ้าย (Left) …………………เซนติเมตร

Leg length difference…………………เซนติเมตร

4. ท่านมีกิจกรรมการออกกำลังกายอื่นนอกจากการวิ่งหรือไม่

❑ ไม่มี ❑ มี

ถ้ามี (โปรดระบุ)

1……………………………………ใช้เวลา………………นาที/วัน, จำนวนวัน…………สัปดาห์

2……………………………………ใช้เวลา………………นาที/วัน, จำนวนวัน…………สัปดาห์

3……………………………………ใช้เวลา………………นาที/วัน, จำนวนวัน…………สัปดาห์

ส่วนที่ 2 ข้อมูลเกี่ยวกับการวิ่ง

1. ท่านทำการวิ่งเป็นประจำมาแล้วเป็นระยะเวลา ………………ปี ………………เดือน
2. ความถี่ในการวิ่ง

❑ 1 วัน/สัปดาห์ ❑ 2 วัน/สัปดาห์ ❑ 3 วัน/สัปดาห์ ❑ 4 วัน/สัปดาห์ ❑ 5 วัน/สัปดาห์ ❑ 6 วัน/สัปดาห์ ❑ 7 วัน/สัปดาห์

3. ระยะเวลาที่วิ่งแต่ละครั้งประมาณ…………………..นาที
4. ระยะทางในการวิ่ง (เฉลี่ย) …………………………กิโลเมตร/วัน

รวมระยะทางในการวิ่งทั้งหมดประมาณ …………………กิโลเมตร/สัปดาห์

ส่วนที่ 3 ข้อมูลเกี่ยวกับการสุขภาพและการบาดเจ็บ

1. ในช่วง 1 ปีที่ผ่านมา มีการบาดเจ็บหรือไม่ ❑ ไม่มี ❑มี (โปรดระบุ)

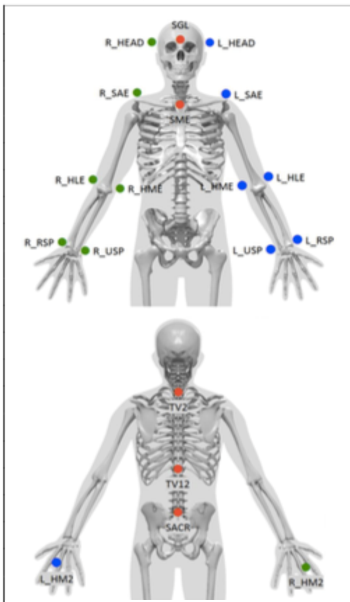
	บริเวณที่บาดเจ็บ	**ระยะเวลาที่บาดเจ็บ**		**มีผลต่อการวิ่ง**		**การรักษา**		
		เริ่มเจ็บ ว/ด/ป	**หายเจ็บ ว/ด/ป**	**มี**	**ไม่มี**	**รักษาเอง**	**พบแพทย์**	**กายภาพบำบัด**
1								
2								
3								
4								
5								

APPENDIX B

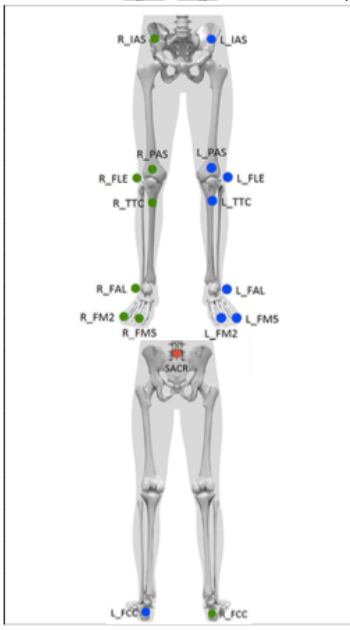
APPENDIX B

Thirty–six spherical retro-reflective markers are placed on anatomical landmarks and segment to define joint motion in full body movement that follow the Project Automation Framework Model (PAF). Three different marker sets will be used, all of which has a proven record of being used in well-established gait labs (Leardini et al., 2007). (Appendix B)

Qualisys PAF Running Package Marker Set



Name	Ref. [1]	Location	Static (35)	Dyn. (35)
L_HEAD		On headband, just above ear	X	X
R_HEAD		On headband, just above ear	X	X
SGL	SGL	On headband, Forehead	X	X
SME	SME	Sternum	X	X
TV2	TV2	Spine, 2nd Thoracic Vertebra	X	X
TV12	TV12	Spine, 12th Thoracic Vertebra	X	X
SACR	(IPS)	Sacrum	X	X
L_SAE	SAE	Shoulder	X	X
L_HLE	HLE	Elbow (outside)	X	X
L_HME	HME	Elbow (inside)	X	X
L_RSP	RSP	Wrist (thumb side)	X	X
L_USP	USP	Wrist (pinkie side)	X	X
L_HM2	HM2	Hand (basis of Forefinger)	X	X
R_SAE	SAE	Shoulder	X	X
R_HLE	HLE	Elbow (outside)	X	X
R_HME	HME	Elbow (inside)	X	X
R_RSP	RSP	Wrist (thumb side)	X	X
R_USP	USP	Wrist (pinkie side)	X	X
R_HM2	HM2	Hand (basis of Forefinger)	X	X



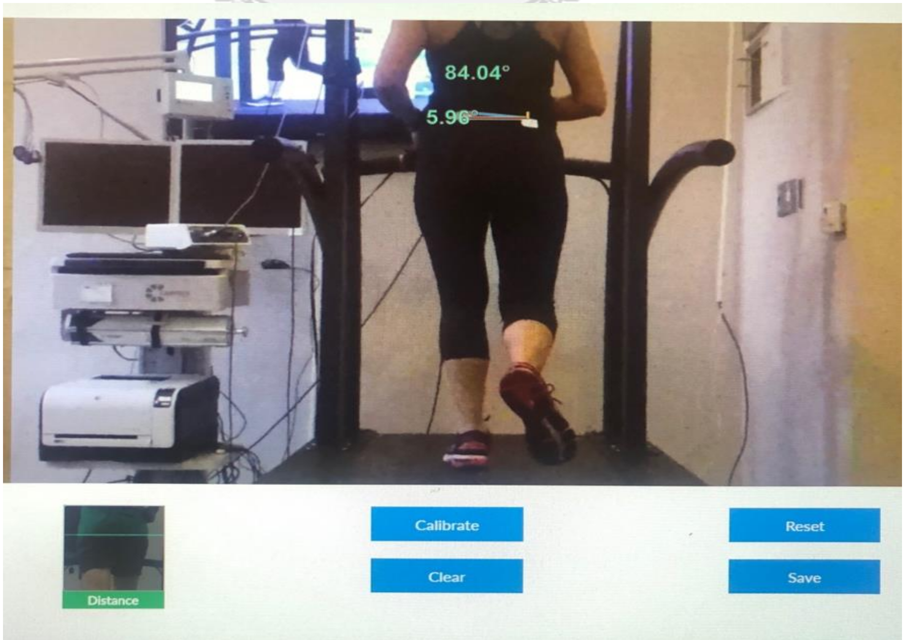
Name	Ref. [1]	Location	Static (35)	Dyn. (35)
L_IAS	IAS	Pelvis (Iliac crest)	X	X
SACR	(IPS)	Sacrum	X	X
R_IAS	IAS	Pelvis (Iliac crest)	X	X
L_PAS		Patella (above knee)	X	X
L_FLE	FLE	Knee	X	X
L_TTC	TTC	Shin	X	X
L_FAL	FAL	Ankle	X	X
L_FCC	FCC	Heel	X	X
L_FM2	FM2	2nd Toe	X	X
L_FM5	FM5	5th Toe	X	X
R_PAS		Patella (above knee)	X	X
R_FLE	FLE	Knee	X	X
R_TTC	TTC	Shin	X	X
R_FAL	FAL	Ankle	X	X
R_FCC	FCC	Heel	X	X
R_FM2	FM2	2nd Toe	X	X
R_FM5	FM5	5th Toe	X	X

APPENDIX C

APPENDIX C

Dynamic pelvic drop test

To assess dynamic pelvic drop test, flat markers (9 mm in diameter) were placed at both sides of Posterior Superior Iliac Spine (PSIS). They were asked to run for 30 minutes on treadmill (Sprintex Natural movement, USA) with Base run (runner's natural pace). Digital video cameras (Sony, Tokyo, Japan) were placed on stand at the back and side of participants and horizontal images were recorded at 30 HZ. The center of back and side camera lens was adjusted to the height of the hip of participants while standing on the treadmill. The researcher recorded the contralateral pelvic drop angle during the last five running cycles every 10 minute and proceeded to evaluate the average angle of pelvic drop during midstance phase by the Kinovea software 0.9.4 version (Kinovea, Korea). The midstance phase was from the lateral malleolus of the swinging leg parallel with the marker on the Lateral Malleolus of the stance leg. If the average pelvis dropped over 5° from PSIS line during running on the non-weight bearing side, the participants were assessed as positive (Huntley, 2003)



APPENDIX D

APPENDIX D

Isokinetic strength testing of hip muscle

The muscle strength of the gluteus medius was measured using isokinetic dynamometry (Biodex System 4 Dynamometer, Shirley, NY, USA). Since the main purpose of this study was to compare the neuromuscular adaptations after training, isokinetic test helped reduce confounding factors due to increases in strength. The test was evaluated for two different types of muscle action, i.e., concentric and eccentric. To evaluate hip strength of concentric and eccentric, 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. The participations were set up following the protocol by Lourencin et al., (2012). Prior to the test, the participants were asked to warm up using 5-minute cycling with freeloading and constant speed. After warm-up, they performed 5 preliminary familiarization trials at a very low intensity. The participants began the test when they felt ready after familiarization. The isokinetic peak torque was normalized to body weight (Nm/kg).

APPENDIX E

APPENDIX E

Motion Analysis system

8 Cameras -200 Hz

Motion capture system Oqus7+, Qualisys AB, Sweden

1 Video base camera

Motion capture system Oqus7+, Qualisys AB, Sweden

HP Cosmos treadmill

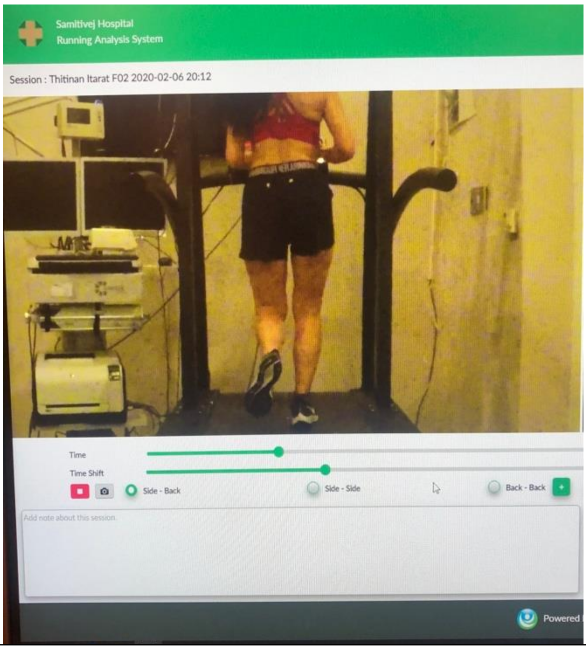
Pluto version, Germany Sweden

36 Reflexive markers

APPENDIX F

APPENDIX F

Equipment of training session



Running Analysis System, Kinovea program, French

32 inches Dell LED monitor,

Sprintex Natural Movement treadmill, USA

52 inches Samsung LED monitor, Korea

Appendix G

Appendix G
The name list of experts of program validation and state IOC values

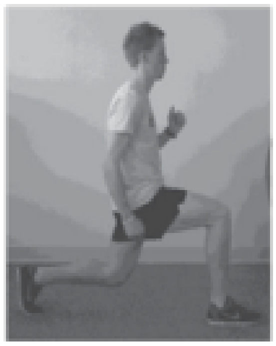
1. Associate Prof. Chathchai Pookarnjanamorakot, M.D.	Orthopedic Surgery–Sports Medical and Arthroscopy Sports & Orthopedic Samitivej Sukhumvit Hospital
2. Professor Prawit Janwantanakul, PT, Ph.D.	Lecturer Department of Physical Therapy Faculty of Allied Health Sciences Chulalongkorn University
3. Suramet Sirijaruwong, M.D.	Rehabilitation Medicine Sports & Orthopedic Samitivej Sukhumvit Hospital
4. Phattarapon Atimetin, M.D.	Medicine of Running Clinic Sports & Orthopedic Samitivej Sukhumvit Hospital
5. Dr.Benjapol Benjapalakorn	Lecturer Faculty of Sports Science Chulalongkorn University

Appendix H

Appendix H

General cardiovascular and dynamic stretching warm up

(Leon et al., 2012)

Name of exercise	Muscles Involved	Description of exercise	
Jogging	General cardiovascular warmup	5 – minute jogging	
March in place	Hip flexor Hamstrings Soleus	Raise one leg to the level of the chest. As the leg is being elevated, hold the front of the knee with both hands and bring the leg toward your chest. The opposing foot will execute a toe lift while you draw your knee as near to your chest as possible. Continue walking for another 20 meters.	
Walking Lunges	Quadriceps Hamstrings Soleus Hip flexors	With a lengthy stride, take a step forward and lower your rear leg to the ground. Concentrate on maintaining your front knee over your ankle and moving slowly and fluidly. Continue walking for another 20 meters.	

Toe Touch Drill	Hip flexors Hamstrings Gluteal Deltoids	Keep one leg extended while swinging it outward and reach out with your opposite hand to contact the toes of the extended leg (or as far down on your leg as you can). Return your leg to its original position and repeat with your other leg and arm. Everything is done in a rhythmic manner throughout this workout. Continue walking for another 20 meters.	
C-Skip Drill	Soleus Hip flexors Gluteal Hamstrings Abductors	Extend the same leg up and straight out at the knee as you go forward with a rapid skipping step, forcing your knee up high. Rep with the other leg after the first has returned to its original position. Continue walking for another 20 meters.	

VITA

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