The effect of a novel movement strategy in decreasing ACL risk factors in female adolescent soccer players

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Abstract

There is a need to investigate the effect of specific movement strategies in reducing biomechanical risk factors for ACL injury in young female athletes. The purpose of this study was 1) to determine the feasibility of implementing a novel movement strategy (Core-PAC) into a team warm-up prior to soccer training based on subject compliance and integration of the Core-PAC into the warm-up and 2) to determine whether the Core-PAC would improve peak knee flexion angles and peak abduction moments at the knee during a side-cut (SC) and an unanticipated side-cut (USC) prior to kicking a soccer ball, and a side-hop (SH) task after immediate instruction and after a four-week training program. A convenience sample of ten 14–16 year old female soccer players were instructed in the Core-PAC immediately after baseline testing and during a training program consisting of a 20-minute warm-up, two-times per week. The Core-PAC was understood and accepted by the subjects and incorporated into their warm-up activities with good compliance. After the immediate instruction, there were significant increases in peak knee flexion angles of a mean 6.4° during the SC ($p = 0.001$), 3.5° during the USC ($p = 0.007$), and 5.8° during the SH ($p < 0.001$) tasks. Peak knee abduction moments decreased by a mean of 0.25 Nm/kg during the SC ($p < 0.03$), 0.17 Nm/kg during the USC ($p = 0.05$), and 0.27 Nm/kg during the SH ($p = 0.04$) tasks. After the 4-week training program, some individuals showed improvement. The results of this study suggest that the Core-PAC may be one method of modifying high-risk movements for ACL injury such as side-cutting and single-leg landing.

Keywords

biomechanics; knee; injury prevention; treatment outcome

INTRODUCTION

Anterior Cruciate Ligament (ACL) injury remains a common and costly challenge for the sports medicine and science community. Every year approximately 250,000 ACL injuries occur at a cost of over 2 billion dollars in the United States (37). More importantly, ACL injuries often result in short and long term disability (12, 22), decreased quality of life (12), and an increased risk of osteoarthritis (22). Female athletes are 4–6 times more likely to suffer an ACL injury while playing multidirectional sports such as soccer and basketball as compared to male athletes (9).

ACL injuries often occur without any direct contact from an opponent during quick decelerations, side-cutting to change direction, or landing from a jump (3, 29). Side-cutting and single-leg landing are frequently performed during multidirectional sports but a typical strategy observed at the time of injury includes: a knee close to extension with a valgus angle and load; an abducted hip with the foot planted in front and lateral to the center of mass (COM); and a trunk that is side-flexed and rotated towards the plant leg (3, 4, 15, 29). These injuries often occur shortly after planting the foot with a perturbation or an unexpected reaction to a game situation at the time of injury (3, 19, 29). The athlete is often observed to be off-balance and to have landed awkwardly with high ground reaction forces that are not dissipated effectively through hip, knee, and ankle flexion (29, 34).

Multimodal training programs have demonstrated improvements in kinematic and kinetic variables during high-risk athletic movements in several laboratory-based experiments (14, 20, 19). However, four studies have looked at the specific effects that technique modification (i.e. modification of high-risk movement patterns) may have on biomechanical variables during high-risk athletic tasks (5, 7, 26, 30) and only one study has looked at the effects of technique modification on side-cutting movements (7). Dempsey et al. (7) investigated the effects of a six-week training program aimed at modifying whole body side-cutting technique in twelve male team sport athletes. Technique modifications included: bringing the foot closer to the midline of the body (i.e. less hip abduction), ensuring the foot was not internally or externally rotated, and maintaining the trunk in an upright, forward facing position. After completing the training program, subjects demonstrated a narrower stance and a more upright trunk on initial foot contact. Importantly, both of these positional modifications were associated with a 36% decrease in valgus moments during the weight acceptance phase of stance. This study demonstrated the potential effectiveness of technique modification on biomechanical risk factors.

The results of Dempsey et al. (7) are important and provide a basis and a rationale to explore other means of technique modification. We propose a novel strategy to reduce biomechanical risk with a method that requires the athlete to move their COM closer to the plant foot with increased trunk control rather than requiring the athlete to attend to and change multiple joint and body segment positions. This movement strategy is referred to as

Core Position and Control (Core-PAC) and the practical application involves the athlete first increasing proximal muscle recruitment and then moving their pelvic centre (focus is often on the navel) in the intended direction of movement such that the COM is positioned as close to the planted foot as possible. Positioning the COM closer to the base of support may bias joint loading to the sagittal rather than the frontal and transverse planes (13, 32). This improved sagittal plane alignment (ankle, knee, and hip in line) may allow the muscles rather than the ligaments to absorb kinetic energy throughout the lower extremity and may result in increased hip, knee and ankle flexion angles (13, 32). Improving an athlete's ability to position their COM over their base of support with increased trunk control may allow them to better respond to unexpected perturbations and to decrease their risk of injury. The Core-PAC results in a similar whole body orientation as described by Dempsey et al. (7), but with a single focus of attention for the athlete that does not involve individual coordination of the upper and lower extremity joints and segments (Figure 1).

The success of an injury prevention program is dependent on the compliance of those using the program and the effectiveness of the program in modifying injury risk factors. Therefore, the purpose of this study was 1) to determine the feasibility of implementing a Core-PAC into a team warm-up prior to regular soccer training based on subject compliance and integration of the Core-PAC into the warm-up and 2) to determine whether the Core-PAC would improve peak knee flexion angles and peak abduction moments at the knee during three dynamic tasks after immediate instruction and after a four-week training program. The three tasks were a side-cut (SC) and an unanticipated side-cut (USC) prior to kicking a soccer ball, and a side-hop (SH) task. It was hypothesized that the feasibility of Core-PAC implementation would be demonstrated by adequate subject compliance and effective implementation of the Core-PAC within a regular soccer team warm-up. It was also hypothesized that the Core-PAC would result in decreased peak abduction moments and increased peak flexion angles at the knee after all three tasks following immediate instruction and after a four-week training program. The Core-PAC may provide an effective technique for coaches and trainers (e.g., athletic trainers, sports physical therapists) to modify movements at increased risk for ACL injury in a field-based, team warm-up.

METHODS

Experimental approach to the problem

A single group pretest-posttest design was used to determine the feasibility of training a Core-PAC within a soccer team warm-up and whether the Core-PAC improves biomechanical risk factors for ACL injury. Subjects completed a supervised 20-minute warm-up two times per week for four weeks, replacing their regular warm-up prior to soccer practice (Table 2). They were instructed to repeat the same warm-up another two times per week as homework on their own. The feasibility of implementing the Core-PAC into a soccer team warm-up was evaluated by a ten-item questionnaire providing feedback from the subjects and the number of training sessions completed was used as an indication of compliance. Peak knee flexion angles and abduction moments at the knee were measured during three dynamic tasks before and after immediate instruction and a four-week Core-PAC training program.

Subjects

Ten female youth soccer players were recruited in January 2007 using a convenience sampling approach from Under 15 and 16 gold level soccer teams. Gold level teams consist of players that are one level lower than the top players for that age group. These ten subjects had similar baseline training experiences and entered the study at the end of their soccer season. Subjects were included if they were: (1) 14–16 years of age; (2) had no injuries for 6 weeks prior to testing; (3) had no medical problems preventing them from participating in the study. They were excluded from the study if they reported any of the following: (1) a previous ACL injury or repair; (2) a back or lower limb injury that kept them from playing or training for greater than 30 days in the past year; (3) presently using a supplemental exercise based training program; or (4) any medical (e.g. infectious disease) or neurologic condition (e.g. concussion, neuropathy, etc.) that would impair their ability to perform the tasks. All subjects' parents provided informed consent and subjects provided assent prior to testing. The University of British Columbia review board granted ethical approval consistent with the appropriate guidelines for the protection of human subjects.

Procedures

Limb dominance was determined by asking the subject with which leg they would prefer to kick a ball. The dominant leg was chosen as the test leg to be consistent across subjects. Subjects wore tight-fitting Lycra shorts and their own running shoes, which were consistent across testing days.

Upon completion of set-up and measurement of anthropometric data (Table 1), subjects were allowed three to five practice trials of the SC. They then performed 9 consecutive SC trials using their own strategy. This procedure was then repeated for the USC and SH (total 27 trials). Immediately after these 27 trials, subjects were instructed on how to perform the same tasks using the Core-PAC and performed an additional 9 trials of each of the 3 tasks using this specific strategy. The subjects were retested a final time (9 trials of each of the 3 tasks) after the four-week long Core-PAC training program. The Core-PAC training program consisted of instruction by a physical therapist and practice of the strategy two times per week during their normal soccer warm-up. In addition, subjects practiced the strategy another two times per week at home without instruction or supervision. The practice trials allowed an adaptation period to minimize variability due to learning effects. The number of practice and performance trials has been shown to be sufficient to capture true landing performance with minimal fatigue and variability influencing performance (6).

Performance Tasks

The performance tasks were performed in the following order-

Side-cut (SC)—To perform the SC, the subject started with her feet in a staggered stance position with the right foot 50 cm in front of the left (Figure 2a). The left foot was positioned 50cm to the left and 83, 93, or 103 cm behind the centre of the force plate, depending on whether the subject's height fell between 150–160, 160–170, or 170–180 cm, respectively. These distances were selected to allow subjects of different heights to perform similar movements and to challenge them to get their centre of mass (COM) initially over

their right foot as it contacted the force plate and then to move their COM to their left foot as they kicked the ball. A soccer ball was positioned at a distance 80% of the subject's height away from the centre of the force plate and at an angle 55° counterclockwise to the plane of progression. This angle has been used effectively in previous studies (1, 2, 25). Standardized instructions were given to each subject to step backwards with her right foot and then stride forward so that her entire right foot landed on the force plate before kicking the ball into the net with her left foot (Figure 2b). As the subject stepped back with her right foot a laser beam was broken to initiate the start of data collection for the trial.

Unanticipated Side-cut (USC)—For the USC task, the subject assumed the same starting position as during the SC trials (Figure 2a). A second ball was positioned 80 cm from the centre of the force plate and at an angle of 15° counterclockwise to the plane of progression (positioned to the right of the first ball). Standardized instructions were given to each subject as per the SC trials except that now the direction arrows would indicate whether to kick the ball on the left or the right with the right foot. The direction arrow was triggered when the subject stepped back with the right foot and appeared on a monitor positioned at approximately chest height, 275 cm forwards of the centre of the force plate. If the subject received a left arrow she had to perform a SC to kick the ball on the left, just as in the preceding SC trials. If she received a right arrow, she had to perform a cross-over cut (across her body) to kick the ball on the right. Test trials were randomized to either direction, ensuring an unanticipated component to the task and the appearance of the arrow was timed so as to force the subject to react quickly. Only the side-cutting (left arrow) and not the cross-over cutting (right arrow) kicks were used for analysis as the former are more commonly involved in ACL injury mechanisms (3).

Side-hop (SH)—To perform the SH, the subject started with her left foot on the outer edge of a line marked at a distance of 70% of the subject's height directly to the left of the centre of the force plate. The right foot was positioned slightly closer than hip-width apart from the left foot (Figure 2a). Standardized instructions were given to each subject to hop onto the force plate, landing on the right foot, and then hop back to the starting position, landing on the left foot (Figure 2c).

Core-PAC instruction—The Core-PAC movement strategy includes a proximal to distal movement sequence, which has been described by several authors relative to enhancing force and speed production (18, 33) and precision and control (18) of the distal segments of the extremities. The Core-PAC instruction involves a sequence of neuromuscular recruitment and segmental movements that begin proximally, or at the trunk/pelvis, followed by movement in the periphery (18, 33, 35).

Instructions such as “keep your knees over your toes”, “bend your knees”, and “bring the stance foot toward the midline of the body” that focus the attention of the athlete on their limbs have been shown to be less effective in learning a complex skill than a focus on a single end point outside of the body (40). A styrofoam ball was used as a training tool to provide this single end point. Although most of the motor control literature describes the effectiveness of this external focus relative to an object such as a golf club or baseball bat (40) a focus on the styrofoam ball serves a similar function. After completing the three tasks,

a styrofoam ball was placed just above the center of the subject's pelvis (pubic symphysis) using an elastic belt.

The subject was first instructed to draw the ball in toward the lumbar spine using a “kegel-type” recruitment pattern of the pelvic floor and transversus abdominus muscles and to maintain this recruitment throughout the movement (35). They were then instructed to push off the left leg and lead with the Styrofoam ball so that the ball would end up over the force plate prior to moving the Styrofoam ball in the direction of the kicking movement. This was in contrast to a reaching type movement wherein the right leg would lead the movement resulting in the right foot contacting the force plate in front and lateral to the COM (Figure 1). Visual and verbal cues were used to explain and demonstrate the Core-PAC and correct the subjects' movements until they consistently demonstrated the new technique. The subjects would then practice the technique for as many times as they needed to feel comfortable and were observed to maintain the new pattern. The total time for instruction and practice varied between 6 to 10 minutes per subject. The three tasks were then repeated as above with the only difference being that the subjects attempted to complete the tasks using the Core-PAC. The subjects were reminded once every four trials to maintain the new strategy. To prevent fatigue, subjects adhered to a work/rest time ratio of at least 1:5 (16). With each trial taking a maximum of two seconds to complete, subjects were given rest periods of ten seconds (minimum) between each trial. On average, the testing procedures took two hours to complete.

Training—Subjects were lead by a physiotherapist through a 20-minute warm-up two times per week for four weeks, replacing their regular warm-up prior to soccer practice (Table 2). They were instructed to repeat the same warm-up another two times per week as homework on their own and to keep a daily journal of their compliance and any comments or questions. The warm-up consisted of standard components that were part of the player's regular warm-up and are recommended as part of effective injury prevention warm-up programs (23, 28). These components included core stability, balance, multidirectional running, and changes of direction (Table 2). The content and intensity of the warm-up allowed for integration of the Core-PAC into functional athletic movements without creating a training stimulus for strength or plyometric power. For example, the focus of the hops and the lunges was on the movement rather than maximal effort for power and strength gains. Subjects wore the Styrofoam ball during the scheduled sessions but not for the homework sessions. The Core-PAC was consistently reinforced throughout the warm-up but no other instructions regarding technique were provided (i.e. “bend your knees”, “keep your knee over your toes”). Subjects were aligned in pairs so that they could observe and correct each other on their Core-PAC technique. This method of partner observation and correction of each other's technique has been used to good effect in previous studies (28). The three performance tasks that were tested in the laboratory were not included in the content of the warm-up. The Styrofoam ball was not used and no reminders or mention of the Core-PAC were given during the post-training testing sessions.

Questionnaire—After completing the training program, an 8-item questionnaire was given to each subject to ascertain whether they thought the program was effectively

instructed and implemented and to provide feedback on the importance and practicality of the Core-PAC for them. The questionnaire consisted of forced-choice questions, such as circling either “yes” or “no”, and an opportunity to explain. Some examples of questions included in the questionnaire were “Did you feel you had enough instruction for the technique?”, “Did you feel you had enough time to practice the technique?”, and “Do you feel this is an important skill to have as an athlete?”.

Data collection—An Optotrak® 3-D motion analysis system (Optotrak 3020, NDI, Waterloo, Canada) was used to track 12 markers (infrared emitting diodes - IREDs) attached to the subject’s lower extremity and pelvis as described by Jian et al (17) and Eng and Winter (8) to generate a 3-D model of the lower body. Marker attachment sites were located over bony landmarks as much as possible to minimize the effects of marker movement. The other foot markers were placed directly on the shoes.

Standardized joint coordinate systems for each segment were defined using digitized landmarks and three non-collinear markers were used to track each body segment during movement. Kinematic data were collected for four seconds with the subject standing with feet hip width apart in a static neutral position to define the zero position. Kinematic data were sampled at 120Hz. Ground reaction forces were collected using a force platform (Bertec, Columbus, Ohio) embedded in the ground along the plane of progression. Force plate data were sampled at 600 Hz and synchronized with the Optotrak system.

Data analysis—Three-dimensional motion data were processed and filtered using custom algorithms (Matlab, Version 14, The Mathworks, Inc., Natick MA). Data were filtered using a Butterworth filter (4th-order, zero-lag, low pass cut-off at 10Hz). Knee angles were defined using the Cardan sequence (extension / adduction / internal rotation) and describe the motion of the distal segment relative to the proximal segment (10).

Trials were excluded during testing if the subject’s whole foot did not land on the force plate or if she did not perform the task correctly (e.g. hesitating to receive the directional cue before kicking). Additional trials were excluded if markers were missing at the start or end of the stance phase or there was more than 10mm of motion between the markers on each limb segment. The kinematics of all remaining trials were time normalized to 100% of the stance phase. If there were more than seven acceptable trials for a subject during analysis, the first seven were chosen.

A 3-D inverse dynamics solution was used to estimate the forces and moments at the joints starting at the most distal joint (39). Knee abduction moments were included in our kinetic analysis and were defined as external moments at the knee (i.e. forces producing an abduction or resisting an adduction angle at the knee). Peak abduction moment was analyzed during the first 20% of stance phase because most non-contact ACL injuries occur during this phase (3) and abduction moments are greatest during this phase (1). This period has also demonstrated increased valgus moments in female compared to male athletes (31). We have shown acceptable test-retest reliability for peak knee flexion angle (ICC=0.88–0.95, SEM range = 1.0°–1.9°) and peak knee abduction moments (ICC=0.62–0.84, SEM range = 0.10–0.23 N·m/kg) across these three tasks (in review).

Statistical analyses

Statistical analyses were done using PASW Statistics 18 (SPSS Inc., Chicago IL). Means and standard deviations were calculated for peak flexion angles and peak abduction moments at the knee for the SC, USC, and SH tasks at baseline, after immediate instruction, and after the four-week training program. A paired-samples t-test was conducted and effect sizes calculated to determine the effects of immediate instruction on baseline peak flexion angles and abduction moments for nine subjects. Statistical significance was set at $p < 0.05$. Statistical analysis was not done on change values after the training program due to a small sample size ($n=7$). Therefore, data is presented in graph form to show changes of all seven individual subjects.

RESULTS

All ten subjects completed the baseline testing but data were not retrievable for one subject after immediate instruction (mechanical error). Seven subjects were tested after the training program (two subjects were injured early in the training while participating in unrelated activities and one subject was not available for post-training testing). The average time between the end of the training program and the post-training test sessions was 6.7 ± 3.5 days (mean $\pm$ SD). All ten subjects selected the right leg as their dominant leg. Therefore, biomechanical and statistical analyses were performed on the right lower limb only. The speeds for the group in completing the three tasks were similar between baseline, immediate instruction, and post-training (Table 3). After removing incomplete trials (e.g. missed force plate data), we used an average of 7.1 SC trials, 7.1 USC trials, and 7.3 SH trials from the original nine trials captured for each subject. This represented 80% of all collected data.

Feasibility; Compliance

Of the seven subjects completing the four-week training program, 49 out of 56 (88%) of the physiotherapist lead training sessions were attended and 50 out of 56 (89%) homework sessions were completed. When asked through the confidential questionnaire at the end of the program, “What did you find most difficult about the training?” all seven subjects chose “time to do it” rather than “technique required” or “physically taxing” as their response.

Core-PAC integration into warm-up

The Core-PAC appeared to be effectively integrated into the content of a 20-minute warm-up before regular soccer practices. Review and demonstration of the Core-PAC at the soccer field took 10 minutes prior to the warm-up for the first two practice sessions. After this, the warm-up was not extended or stopped for additional instruction or clarification of the Core-PAC. Within the questionnaire, all seven subjects felt that overall there was adequate instruction and enough time to practice the Core-PAC and subjects perceived the warm-up demand as no greater than a regular soccer warm-up.

Immediate instruction (n=9)

Kinematics—A typical kinematic profile across the three tasks showed subjects landing on the force plate in approximately 20–40° of knee flexion angle with the knee increasing to peaks of 55–70° flexion at mid-stance before decreasing to 10–30° flexion at the end of

stance (Figures 3a–c). Peak knee flexion angles occurred at similar time points within mid stance for all three tasks during baseline, immediate instruction, and post-training sessions. There were significant increases in peak knee flexion angles of a mean 6.4° during the SC ($t(8) = 4.94$, $p = 0.001$, $ES = 1.14$), 3.5° during the USC ($t(8) = 3.62$, $p = 0.007$, $ES = 0.61$), and 5.8° during the SH ($t(8) = 6.39$, $p < 0.001$, $ES = 1.07$) tasks after the immediate instruction (Table 3). Changes in angles across tasks are demonstrated for a typical subject in Figure 3a–c.

Kinetics—Across all three tasks, subjects demonstrated bimodal peak in abduction moment; the first, sharper peak of 0.75–1.75 Nm/kg occurring between heel contact and 20% of stance phase and a second, lesser or equal, more gradual peak at the end of stance during push-off phase with moments between the two peaks decreasing between 70% of peak moment to similar base-line levels as those occurring at initial contact (Figure 3d–f). Peak knee abduction moments always occurred within the first 20% of stance for all three tasks during baseline, immediate instruction, and post-training testing sessions. Peak knee abduction moments decreased by a mean of 0.25 Nm/kg during the SC ($t(8) = 2.58$, $p < 0.03$, $ES = -1.04$), 0.17 Nm/kg during the USC ($t(8) = 2.36$, $p = 0.05$, $ES = -0.69$), and 0.27 Nm/kg during the SH ($t(8) = 2.50$, $p = 0.04$, $ES = -0.67$) tasks (Table 3). Changes in abduction moments across tasks are demonstrated for a typical subject in Figure 3d–f.

Training program (n=7)

Kinematics—During the SC task, five of the seven subjects demonstrated increased peak knee flexion angles (range = 1 to 14°) with three subjects demonstrating increases of over 5° . In contrast, two subjects showed small decreases of 1° each after the four-week training period (Figure 4a–c). During the USC, four of seven subjects showed an increase (range = 4 to 11°) and three subjects showed a decrease (range = 1 to 4°) in peak flexion angles. Three subjects showed an increase (range = 4 to 12°) and four subjects showed a decrease (range = 1 to 7°) in peak flexion angles during the SH task.

Kinetics—After the four-week training period for the SC task, five of the seven subjects decreased peak abduction moments (range = 0.07 to 0.55 Nm/kg), with four of the seven decreasing by over 0.17 Nm/kg. In contrast, two subjects increased their peak abduction moment by 0.08 and 0.22 Nm/kg (Figure 4d–f). During the USC, five of the seven subjects decreased peak abduction moments (range = 0.13 to 0.43 Nm/kg), one subject did not change, and one subject increased by 0.12 Nm/kg. During the SH task, six of the seven subjects decreased peak abduction moments (0.04 to 0.79 Nm/kg), with four decreasing by more than 0.29 Nm/kg. In contrast, one subject increased by 0.28 Nm/kg.

DISCUSSION

Feasibility

The findings of our study support our main hypothesis that implementation of a Core-PAC into a team warm-up prior to regular soccer training is feasible. Compliance of the training program was excellent with attendance close to 90% for the instructed and the self-directed training sessions, much higher than those reported in other studies (38). The Core-PAC

appeared to be effectively implemented into the team warm-up without disrupting the flow or the physiological benefits of the warm-up. Subjects were able to quickly understand and incorporate the Core-PAC into the warm-up and were satisfied with the mode of instruction and amount of practice. These observations and feedback are important practical considerations when implementing an injury prevention program because compliance is one of the greatest challenges to the success of injury prevention programs (27, 38). With respect to feasibility, the findings of this pilot work are important to consider when designing future controlled trials investigating methods to change movement, such as the Core-PAC.

Some recent studies using technique modification have demonstrated improvements in biomechanical risk factors during typical movements that increase risk of ACL injury (5, 7, 26, 30). However, instructions are typically focused on modifying several joint and body positions (7, 26, 30) which may not be the most effective method of changing complex movements compared to a single end point focus (40). The Core-PAC is a novel movement strategy that utilizes a single end point focus (centre of mass position relative to the knee) which may provide the coach and the athlete with a simpler means of instructing, learning, and monitoring changes in movement strategy.

Immediate instruction

Our second hypothesis was also supported by the results of this study. Significant increases in peak flexion angles and decreases in peak abduction moments were demonstrated across tasks after the immediate instruction of the Core-PAC.

The significant improvements in peak flexion angles and peak abduction moments after immediate instruction across the SC, USC, and SH tasks are a novel finding. Previous drop jump and jump landing studies used specific instructions and feedback to increase bending of the knees upon landing (5, 26, 30). In the current study, instruction of the Core-PAC did not include any reference to the knee position. An increase in peak knee flexion angle and decrease in peak abduction moment after the Core-PAC instruction was achieved by encouraging subjects to move their COM closer to their base of support (planted foot) which may have transferred more joint loading to the sagittal rather than the frontal and transverse planes (13, 32).

Training program

After the four-week training program, subjects generally improved in both of our biomechanical variables across all three tasks. These results are encouraging considering our initial uncertainty of how effective the Core-PAC instruction would be in a practical, field-based setting as compared to the controlled laboratory environment.

The post-training results should be considered in the context of several factors. First, there were no reminders or demonstrations for the subjects of the Core-PAC prior to the post-training testing sessions, which took place between 2 and 11 days after the end of the training program. Instruction of the Core-PAC on the field during a team warm-up is practical but potentially less effective compared to individual instruction in the laboratory. We chose to explore the effects of this instruction within a realistic and practical setting for a youth sports team. The training program did not include the SC, USC, or SH tasks because

we wanted to evaluate the transfer of the training program effects to unpracticed tasks. Transfer of a movement strategy from one task to another, along with retention, are means of evaluating learning rather than the short-term performance of a skill (36). In light of the above considerations, the modest improvements demonstrated after the training period is encouraging.

There is consensus in the literature that a combination of forces is most likely to injure the ACL (11, 24). Both anterior translation and abduction moments are reduced with increasing knee flexion angles (11, 24). However, we do not know what combinations or degrees of change in flexion angles and abduction moments are clinically relevant and how this interacts with other variables such as transverse plane biomechanics and the effects of neuromuscular control. For the majority of subjects, the Core-PAC led to improvements in both the peak flexion angle and peak abduction moment, particularly for the immediate instruction condition.

The current study has several limitations. First, we initiated the study with a small sample size ($n=10$) that was further compromised by three dropouts for the post-training testing. However, it was a homogeneous sample that was representative of the age and characteristics of the population most at risk for non-contact ACL injuries. There was no control group to compare the changes that may have resulted from implementation of the Core-PAC during either testing session. We also cannot discount the effects that other parts of the warm-up (core strength, balance, lower extremity strength, or agility) may have had on our results. However, these other components were performed at a volume and intensity that were similar to the subjects' regular warm-up except for a focus on the movement technique. Subjects confirmed that the demand was not greater than their regular soccer warm-up through the questionnaire provided at the end of the training program. Four weeks may not have been long enough to learn the Core-PAC and transfer it to unpracticed tasks after a retention interval. Finally, we do not know how well these effects would transfer to a competitive, "real-world" sport setting. Perhaps the Core-PAC should be taught and reinforced during practice and game situations. This may provide for the most practical and direct application of a movement strategy intervention as it offers more time to practice in a real world environment without taking additional time from the athletes or the coaches. These are all important considerations in increasing compliance of an intervention (27, 38).

PRACTICAL APPLICATIONS

The results of this study suggest that the Core-PAC may be one method of modifying high-risk movements such as side-cutting and single-leg landing. The Core-PAC was feasible and successfully implemented into a team warm-up prior to regular soccer training. It appeared that the Core-PAC was easily understood and accepted by the subjects and incorporated into their warm-up activities and self-directed homework sessions with good compliance. The Core-PAC also demonstrated improvements in biomechanical risk factors after immediate instruction and showed improvement in some individuals after a four-week training program. Therefore, the Core-PAC shows promise for coaches and trainers to use as a means of modifying technique in high-risk movements for ACL injury. The Core-PAC instructions allow for a practical means of technique modification during field-based, team warm-ups.

These preliminary results warrant further investigation to build on this work and ascertain the potential isolated effects of the Core-PAC in reducing biomechanical risk factors

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Figure 1. Core-PAC (proximal to distal) vs. reach (distal to proximal) movement strategy
1a) A distal to proximal or “reaching” movement resulting in hip abduction and ipsilateral trunk side-flexion with the COM at a distance from the planted foot. **1b)** Correction of the reaching movement by a Core-PAC strategy focused on getting the COM (styrofoam ball=white circle), over the planted foot. **1c)** An alternative correction of the reaching movement by bringing the foot under the midline of the body and straightening the trunk.

Figure 2. Diagram of experimental set-up and movement tasks tested

The laser beam was broken as the subject stepped back with her right foot, triggering the start of timing for SC and USC and the direction arrow for USC. The subject then stepped forward with her right foot onto the force plate followed by a side-cut to kick the soccer ball (L) into a net on the left for SC and USC or used a cross cut to kick the soccer ball (R) into a net on the right for the USC (not analyzed or shown here). **SH Task:** Starting with both feet on the ground, the subject hopped onto the force plate, landing on the right foot, and then hopped back to the starting position, landing on the left foot.

Figure 3.

Mean changes in peak flexion angle (a, b, c) and peak abduction moment (d, e, f) during the three movement tasks for a sample subject

Figure 4.

Individual changes in peak flexion angles (a, b, c) and abduction moments (d, e, f) by task and subject number for baseline (Base) to immediate instruction (Imm), and from Base to post-training (Post) testing sessions.

TABLE 1

Subject characteristics (n=10).

Characteristic	Mean	SD	Range
Age (years)	15.1	1.3	14–17
Height (m)	1.64	0.05	1.58–1.71
Weight (kg)	58.3	11.4	43.8–76.1
BMI (kg/m ²)	21.5	3.3	17.3–26.1

TABLE 2

Warm-up exercises.

Warm-up:	
Slow jog	× 1 lap (full field)
Core set	5 × 10 seconds
Jog with diagonal push offs	× 1 lap (ends = stop and go / lengths = cutting from a jog)
Lateral shuttle	4 slow / 4, 3, 2, 1 fast
Core cross bar	3 × 10 second hold – progress as tolerated
Balance with rotation	3 × 20 sec / each leg
Diagonal lunges	2 widths
Lateral hops	3 × 10 hops
Diagonal hops	3 × 10 hops

TABLE 3

Effects of immediate instruction and training on peak flexion angles and abduction moments for the side-cut, unanticipated side-cut, and side-hop tasks
(mean $\pm$ standard deviation)

	Peak flexion angles(°)			Peak abduction moments(N·m/kg)			Average speed of movement(m/s)					
	Side-cut	Unanticipated	Side-cut	Side-hop	Side-cut	Unanticipated	Side-cut	Side-hop	Unanticipated	Side-cut	Side-hop	
Results following immediate instruction												
	Pre-test (n=9)			59.1 ± 4.8	61.8 ± 4.9	62.7 ± 5.0	1.09 ± 0.27	1.18 ± 0.24	1.52 ± 0.48	2.76 ± 0.21	2.65 ± 0.38	2.63 ± 0.21
	Immediate Instruction (n=9)			65.5 ± 5.8	65.3 ± 6.0	68.5 ± 5.3	0.84 ± 0.18	1.01 ± 0.23	1.25 ± 0.26	2.70 ± 0.18	2.61 ± 0.32	2.62 ± 0.22
	Pre-test-Immediate Instruction Difference			6.4	3.5	5.8	-0.25	-0.17	-0.27	-0.06	-0.04	-0.01
Strength Cond Res. Aut												
Results following weeks training												
	p-value			0.001	0.007	0.000	0.033	0.046	0.037			
	Pre-test (n=7)			60.7 ± 4.7	64.1 ± 4.6	64.7 ± 4.9	1.02 ± 0.32	1.17 ± 0.23	1.5 ± 0.54	2.84 ± 0.08	2.82 ± 0.25	2.73 ± 0.16
	Post-test (n=7)			65.0 ± 7.7	66.8 ± 6.9	65.5 ± 8.5	0.84 ± 0.07	1.00 ± 0.15	1.21 ± 0.33	2.75 ± 0.22	2.80 ± 0.23	2.74 ± 0.15
Pre-test-Post-test Difference			4.3	2.7	0.8	-0.18	-0.17	-0.29	-0.09	-0.02	+0.01	