The Effect of a Novel Movement Strategy in Decreasing ACL Risk Factors in Female Adolescent Soccer Players: A Randomized Controlled Trial

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Abstract

Objective—To determine the effect of a novel movement strategy incorporated within a soccer warm-up on biomechanical risk factors for ACL injury during three sport-specific movement tasks.

Design—Single-blind, randomized controlled clinical trial.

Setting—Laboratory setting.

Participants—20 top-tier female teenage soccer players.

Interventions—Subjects were randomized to the Core Position and Control movement strategy (Core-PAC) warm-up or standard warm-up which took place prior to their regular soccer practice

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over a 6-week period. The Core-PAC focuses on getting the centre of mass closer to the plant foot or base of support.

Main Outcome Measures—Peak knee flexion angle and abduction moments during a side-hop (SH), side-cut (SC) and unanticipated side-cut (USC) task after the 6-weeks with (intervention group only) and without a reminder to use the Core-PAC strategy.

Results—The Core-PAC group increased peak flexion angles during the SH task (Mean difference = 6.2°, 95% CI: 1.9–10.5°, effect size = 1.01, $P = 0.034$) after the 6-week warm-up program without a reminder. In addition, the Core-PAC group demonstrated increased knee flexion angles for the side-cut (Mean difference = 8.5°, 95% CI: 4.8–12.2°, ES = 2.02, $P = 0.001$) and side-hop (Mean difference = 10.0°, 95% CI: 5.7–14.3°, ES = 1.66, $P = 0.001$) task after a reminder. No changes in abduction moments were found.

Conclusions—The results of this study suggest that the Core-PAC may be one method of modifying high-risk soccer-specific movements and can be implemented within a practical, team-based soccer warm-up. The results should be interpreted with caution due to the small sample size.

Keywords

biomechanics; knee; injury prevention; treatment outcome

INTRODUCTION

Multidirectional sports, such as soccer, are among those most likely to result in anterior cruciate ligament (ACL) injury^{1,2} and young women participating in these sports are four to six times more likely to sustain an ACL injury as compared with young men.³ There is growing evidence that neuromuscular training can change movement patterns that improve biomechanical risk factors and can decrease the incidence of ACL injuries in female athletes.^{4,5} Most of these training programs are multimodal and include components of strength, balance, plyometrics, flexibility and technique. However, there is a need to understand the separate effects of each of these components in modifying high-risk movements. Several single-group pretest-posttest studies have suggested that it may be possible to modify body positions during high-risk athletic tasks using technique modification or instruction.^{6–8} Only one study has utilized a rigorous randomized controlled trial; Onate et al.⁹ found that instruction of a basketball jump-landing technique was successful in reducing vertical peak forces.

We propose a novel movement strategy which focuses on transferring the centre of mass (COM) closer to the plant foot or base of support (BOS). This Core Position and Control (Core-PAC) movement strategy may be one method of modifying high-risk movements such as side-cutting and single-leg landing. The novel aspect of the Core-PAC is that the upper and lower extremity joints and segments are coordinated with a single focus of attention for the athlete (Figure 1). The athlete first increases proximal muscle recruitment and then moves 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. The Core-PAC results in a similar whole body orientation achieved by the technique modifications described by Dempsey et al.⁷, but with a single focus of attention.

Moving the COM closer to the BOS may result in a shift in the proportion of total joint loading to the sagittal rather than the frontal and transverse planes. Frontal and transverse plane loading often occurs in female athletes that are at risk for ACL injury.^{10,11} In a previous single-group pretest-posttest study we demonstrated that the Core-PAC was feasible and demonstrated improvements in biomechanical risk factors after immediate instruction.¹² In addition, the Core-PAC was successfully implemented into a team warm-up prior to 4 weeks of regular soccer training.¹²

In this study, we conducted a randomized controlled trial to determine the effect of the Core-PAC warm-up prior to 6 weeks of regular soccer training for peak 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. It was hypothesized that the Core-PAC group would have greater peak flexion angles and lower peak abduction moments at the knee compared to a control group at the end of the 6 weeks.

METHODS

Design

This study was a randomized controlled trial.

Subjects and Recruitment

Figure 1 shows the subject flow diagram. Participants were recruited from two female soccer teams (one Under-15 and one Under-16 years old) in March, 2007. The teams consisted of top provincial-level players whose injury risk was higher due to age and gender.^{13,14} Subjects were included if they were: (1) 14–16 years of age; (2) had no injuries for six 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 training for greater than 30 days in the past year; (3) using a supplemental exercise based program; or (4) any medical condition that would impair their ability to perform the tasks. Informed consent was obtained and ethical approval was granted by the university and the full protocol is available from the authors.

Randomization and Allocation Concealment

A total of twenty players met the inclusion criteria and were randomly allocated to either the intervention (Core-PAC) group or the control group using concealed allocation. Each subject was assigned a subject code tag which was put in an envelope. A second envelope contained 10 treatment and 10 control tags. An individual independent of the study drew a subject code and then group assignment tag until all subjects were assigned to either the control or the intervention group. Therefore, the Core-PAC group and the control group were each made up of players from both of the two female soccer teams. Research personnel who tested subjects and analyzed data were also blinded to group allocation. The physiotherapists providing the warm-up were not blinded. Concealment of group assignment was maintained until data were collected during the second set of post-training testing sessions (posttest 2).

Procedures

The dominant leg (preferred kicking 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 assessments.

During the baseline biomechanics test, subjects from both the Core-PAC and control groups performed three to five practice trials prior to performing nine consecutive test trials of each of the three performance tasks (SC, USC, and SH) using their own strategy. After 6-weeks, subjects were retested (post-test 1) with the same baseline instructions. After completing the three tasks, another practice session was undertaken prior to post-test 2. The intervention group was asked to practice the tasks for 2–3 minutes using the Core-PAC strategies, while the control practiced the tasks for 2–3 minutes using their usual strategies. Then post-test 2 took place where the control was provided with the same baseline instructions while the intervention group was reminded to use Core-PAC strategies (Figure 2).

Performance Tasks—The performance tasks included a single stride rather than a run-up approach to expose the potential “reaching” strategy that results in the base of support (BOS) further from the centre of mass (COM). The intervention was focused on the strategy of positioning the COM closer to the BOS and its effects on knee biomechanics. Although the forces are greater with a run-up, the differences may not be as great between strategies when momentum may result in the COM closer to the BOS. The tasks were performed in the following order and are detailed in Figure 3.

Side-cut (SC): To perform the SC, the subject started with her feet in a staggered stance position. 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.

Unanticipated Side-cut (USC): The subject assumed the same starting position as during the SC trials. 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 (crossover cut across her body) with the right foot. Only the side-cutting (left arrow) kicks were used for analysis because they are commonly involved in ACL injury mechanisms.¹⁵

Side-hop (SH): 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.

Data Collection

Data collection took place at the GF Strong Rehab Centre. An Optotrak©3-D motion analysis system (Optotrak 3020, NDI, Canada) was used to track 12 infrared emitting diodes (3 per segment) attached to the subject’s lower extremity and pelvis to generate a 3-D model of the lower body.^{16,17} 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

Research personnel analyzing the data were blinded to the group allocation. 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). Residual analysis between filtered and unfiltered signals¹⁸ confirmed that the cut-off frequency was appropriate. 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.¹⁹ The kinematics of the first 7 acceptable trials (e.g. feet on forceplate) were time normalized to 100% of the stance phase.

A 3-D inverse dynamics solution was used to estimate the forces and moments at the joints starting at the most distal joint.¹⁷ 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 movement at the knee). Peak abduction moment was analyzed during the first 20% of stance phase because most non-contact ACL injuries occur during this phase¹⁵ and abduction moments are greatest during this phase.²⁰ This period has also demonstrated increased valgus moments in female compared to male athletes.²¹ All trials contained peak moments within the first 20% of stance phase.

Warm-up Routine

Subjects in each group performed a 20-minute on-field warm-up routine four times per week for six weeks, replacing their regular warm-up prior to soccer practice. Both groups were told that they were receiving the same warm-up content but with different instructions. Physiotherapists led the warm-up two times per week. Following attendance at a one-hour instruction session and after receiving training program instruction materials, coaches repeated the same warm-up with their teams an additional two times per week. The coaches were given the same cues and feedback instructions as were used by the physiotherapists.

The warm-up consisted of standard components recommended as part of effective injury prevention warm-up routines.^{22–24} These components included core stability, balance, multidirectional running, and changes of direction (some of which were already part of the player's regular warm-up).

Both groups were matched in the amount and frequency of feedback they received from the physiotherapists and coaches; the physiotherapists and coaches provided encouraging and general feedback such as “good work” and “keep your balance” which attempted to minimize potential biases and confounding variables by not positively or negatively affecting their movement strategy. An audit was conducted once per week to ensure the amount and frequency of feedback was equal between groups.

Warm-up Modifications for the Core-PAC Group

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.²⁵ A styrofoam ball was used as a training tool to provide this single end point. The ball was placed just above the center of the subject’s pelvis (pubic symphysis) using an elastic belt.

The Core-PAC group was 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 all movements.²⁶ They were then instructed to push off the stance or back leg rather than reach with the lead leg; and lead with the Styrofoam ball so that the ball was over or close to the BOS on the new plant leg during all movements within the team warm-up.

Subjects in the Core-PAC group wore the styrofoam ball during the physiotherapist-delivered sessions but not during the coach-delivered sessions. The Core-PAC was reinforced throughout the warm-up with cues such as “move from the centre” and “lead with the belly button”. No other instructions regarding technique (e.g. “bend your knees”, “keep your knee over your toes”) were provided to the Core-PAC group. Subjects were aligned in pairs, where possible, so that they could observe and correct each other’s Core-PAC technique. The subjects in the control group were provided with an equal amount of general instructions such as “keep your balance” and “get to the line”.

Sample Size

Prior to this exploratory RCT, we investigated the feasibility of conducting such a trial with a pilot study. Based on the results of the pilot study (SC mean difference in peak flexion angle = 6.4° (common SD = 5.3) and SC mean difference in peak abduction moment = 0.25 Nm/kg (common SD = 0.22)), 11 to 13 subjects per group would provide a power of 0.80, assuming an alpha of 0.05.¹²

Statistical Analysis

Statistical analyses were carried out using PASW Statistics 18 (SPSS Inc., Chicago IL). Assumptions for normality of distribution for all variables were checked. Assumptions of homogeneity of variance and sphericity were also validated for the use of ANOVA analyses. A two-way mixed ANOVA with a between-subject factor of group (Core-PAC and control) and a within-subject factor of time (baseline, post-test 1, post-test 2) was used to compare differences between groups in peak knee flexion angle and peak abduction moment during the three tasks. This was repeated six times for the two dependent variables (peak flexion angle and abduction moment) across the three tasks (SC, USC, and SH). Main effects for group and time and interaction effect of group x time were calculated. Two-tailed alpha level was set at 0.05.

When significant interactions were identified, post hoc analyses using a univariate repeated measures ANOVA with a Bonferroni correction for multiple comparisons were conducted

separately for the control and experimental groups. Analyses were performed with an intention-to-treat approach; that is all subjects were included despite compliance to protocol

RESULTS

Subjects

At baseline there were no significant differences between groups on study characteristics (Table 1). Twenty subjects completed the baseline testing, with one subject being lost to injury from within the control group. The mean days between the end of the 6-week session and post-test 2 was 8.1 ± 6.2 days. All subjects selected the right leg as their dominant leg. Therefore, statistical analyses were performed on the right lower limb only. The speeds for the groups in completing the three tasks were not significantly different between groups or between baseline and post-test 1 or post-test 2.

Compliance

Subjects in the Core-PAC group completed 87% and 88% of the physiotherapist or coach led warm-up sessions in the Core-PAC and in the control group, respectively. There were no adverse events resulting from the warm-up sessions.

Effect of Core-PAC Routine

Typical changes in flexion angle and abduction moment during the three movement tasks are shown for a representative Core-PAC and control subject before and after the 6-week period (Figure 4). There were significant group by trial interactions for peak knee flexion angle during the SH ($P = 0.001$) and SC tasks ($P < 0.001$). Bonferroni corrected post hoc analyses revealed that the Core-PAC group demonstrated a significant increase in peak flexion angles during the SH (Mean difference = 6.2° , 95% CI: 1.9 – 10.5° , effect size (ES) = 1.01, $P = 0.034$) after the 6-week period (post-test 1) and during the SC (Mean difference = 8.5° , 95% CI: 4.8 – 12.2° , ES = 2.02, $P = 0.001$) and the SH (Mean difference = 10.0° , 95% CI: 5.7 – 14.3° , ES = 1.66, $P = 0.001$) tasks after reminding the subjects in the Core-PAC group to perform the tasks using the Core-PAC strategy (post-test 2).

There was a significant main effect of time for peak knee abduction moment during the SC ($P = 0.022$) and USC ($P = 0.015$). Bonferroni corrected post hoc analyses did not demonstrate significant increases in peak knee abduction moments for the groups at post-test 1 or post-test 2 during SC and USC tasks.

DISCUSSION

This is the first randomized controlled trial to demonstrate improvements in some biomechanical risk factors for ACL injury as a result of isolated movement training implemented within an actual soccer team warm-up. The potential strain on the ACL is decreased with increasing knee flexion angles. An increase in knee flexion angle may offer the ACL some protective mechanism to influence the combination of joint positions and forces that may contribute to an ACL injury. An increase in knee flexion angle may indicate that forces are being transferred to the large muscle groups (gluteus maximus, quadriceps

femoris) in the sagittal plane rather than inert ligamentous structures such as the ACL and the medial collateral ligament (MCL) in the frontal plane.^{10–11}

Previous studies have found that technique modification can result in an increase in peak flexion angles during a jump-landing task when subjects were instructed to bend their knees during training.^{6,8–9} Dempsey et al.⁷ investigated the effects of a 6-week individualized training program (pre-post study without a control group) aimed at modifying whole body side-cutting technique. They demonstrated a 36 % decrease in valgus moments during the weight acceptance phase of stance but did not observe a change in flexion angles at the knee (opposite to our results). During the side hop in our study, increases in flexion angle were evident with or without a reminder, while in the case of the side-cut, increases in flexion angle were only evident after the reminder (post-test 2). It is possible that greater effects may have been observed if the Core-PAC strategies had been reinforced in the actual soccer practice, and not just the warm-up routine.

The Core-PAC group did not decrease peak abduction moments. This is in contrast to our previous findings¹² where we demonstrated significant decreases in peak abduction moments after a reminder. One of the main differences between our two studies was the higher level of soccer played by the subjects in the present study (provincial level) compared to the previous study (community level). It is possible that these elite athletes have more established abduction moment biased movement patterns. Sigward and Powers²⁷ found that increased abduction moments is a characteristic of high level players during side-cut tasks compared to their less experienced counterparts. If abduction movement patterns are less amendable to change, then the increase in knee flexion angle that we demonstrated in our study may be even more important in reducing the combined loading on the ACL. It is also possible that changes to the abduction movement patterns may require more intensive instruction and feedback (e.g., video-recording and replay analysis) to establish change. Donnelly et al.²⁸ found that balance and technique training did not improve knee abduction moments in a “real world” training environment of Australian football players.

LIMITATIONS

The results need to be interpreted with caution due to the small sample size. The small number of subjects may reduce the generalizability of the sample to the wider population of female soccer players. The small trial may have been able to capture large effects, but perhaps some variables (e.g. moments) may have had smaller, but still clinically relevant effects that we could not detect. A further limitation of laboratory-based experiments such as ours is inferring injury risk through the evaluation of non-injurious movements performed in a controlled setting²⁹. While the length of the intervention (6 weeks) is consistent with other neuromuscular warm-up programs that are effective in decreasing ACL injury risk^{7, 30}, we do not know how well the positive effects we did find would transfer to a competitive, “real-world” sport setting or if they are maintained at long-term follow-up. Finally, we had both groups train simultaneously so as to minimize the risks of contamination. However, there was the potential for participants from each group to discuss the differences in instruction and focus outside of the sessions. However, the risk of this was minimal as they performed identical exercises between the two groups and participants did not appear to be aware of

differences between the protocols (e.g., no questions were asked by the teenagers or parents).

CONCLUSION

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 and can be implemented within a practical, team-based soccer team warm-up. The results should be interpreted with caution due to the small sample size.

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Figure 1.
Flow chart of subject through the study.

Figure 2.
Testing and training timeline.

Figure 3.

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 4.

Changes in peak flexion angle (a, b, c) and abduction moment (d, e, f) during the three movement tasks for a representative Core-PAC and control subject before and after the Core-PAC training program (post-test1). Flexion angles are greater in the negative direction and abduction moments are greater in the positive direction. After the training program, this Core-PAC subject shows increased flexion angles across all three tasks and decreased moments during the SH. Conversely, the control subject shown here demonstrates decreased flexion angles across all three tasks, increased peak moments during the SC and SH tasks and decreased peak moments during the USC.

Table 1Subject Characteristics (mean $\pm$ standard deviation (range))

Characteristic	Intervention (n = 10)	Control (n = 9)
Age (years)	15.7 $\pm$ 0.5 (15–16)	15.1 $\pm$ 0.9 (14–16)
Height (m)	1.65 $\pm$ 0.06 (1.57–1.78)	1.66 $\pm$ 0.06 (1.55–1.75)
Weight (kg)	60.9 $\pm$ 5.7 (52.6–72.6)	63.1 $\pm$ 8.2 (52.3–78.0)
BMI (kg/m ²)	22.3 $\pm$ 1.9 (19.4–25.5)	22.8 $\pm$ 1.8 (21.0–25.5)

Post-hoc Tests of Peak Knee Flexion Angles (°) and Abduction Moments (N·m/kg) Between Groups and Across Tasks for the Three Testing Sessions (SD)

Table 2

Variable	Intervention (n = 10)			Control (n = 9)		
	Baseline	PT1	PT2	Baseline	PT1	PT2
<i>Side-cut</i>						
Peak Flexion Angle * $\tau\phi$	60.4 $\blacklozenge$ (5.7)	64.2 (7.2)	68.9 (4.1)	61.0 (5.5)	59.2 (4.7)	59.5 (3.5)
Peak Abduction Moment τ	1.13 (0.26)	1.27 (0.22)	1.23 (0.27)	1.05 (0.32)	1.25 (0.29)	1.32 (0.30)
<i>Unanticipated Side-cut</i>						
Peak Flexion Angle	63.5 (6.2)	67.1 (5.3)	70.1 (4.5)	63.5 (5.0)	62.8 (6.3)	63.2 (4.9)
Peak Abduction Moment	1.11 (0.36)	1.16 (0.38)	1.22 (0.49)	1.00 (0.24)	1.14 (0.32)	1.25 (0.44)
<i>Side-hop</i>						
Peak Flexion Angle * τ	62.6 $\blacksquare$ (4.3)	68.8 (8.6)	72.6 (6.1)	64.3 (5.0)	63.2 (4.8)	63.5 (4.2)
Peak Abduction Moment	1.20 (0.30)	1.25 (0.31)	1.18 (0.27)	1.11 (0.38)	1.35 (0.48)	1.30 (0.33)

Mean(standard deviation); PT1=post-test 1; PT2=post-test 2

* Significant Interaction Effect
 τ Significant Time Effect
 ϕ Significant Group Effect
 $\blacklozenge$ Flexion Angle in Post-test 2 is significantly greater than Baseline
 $\blacksquare$ Flexion Angles in Post-test 1 and Post-test 2 are significantly greater than Baseline