The Effects of an Injury Prevention Program on Landing Biomechanics Over Time

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Background: Knowledge is limited regarding how long improvements in biomechanics remain after completion of a lower extremity injury prevention program.

Purpose: To evaluate the effects of an injury prevention program on movement technique and peak vertical ground-reaction forces (VGRF) over time compared with a standard warm-up (SWU) program.

Study Design: Controlled laboratory study.

Methods: A total of 1104 incoming freshmen (age range, 17-22 years) at a military academy in the United States volunteered to participate. Participants were cluster-randomized by military company to either the Dynamic Integrated Movement Enhancement (DIME) injury prevention program or SWU. A random subsample of participants completed a standardized jump-landing task at each time point: immediately before the intervention (PRE), immediately after (POST), and 2 (POST2M), 4 (POST4M), 6 (POST6M), and 8 months (POST8M) after the intervention. VGRF data collected during the jump-landing task were normalized to body weight (%BW). The Landing Error Scoring System (LESS) was used to evaluate movement technique during the jump landing. The change scores (Δ) for each variable (LESS, VGRF) between the group's average value at PRE and each time point were calculated. Separate univariate analyses of variance were performed to evaluate group differences.

Results: The results showed a greater decrease in mean (±SD) VGRF in the DIME group compared with the SWU group at all retention time points: POST2M (SWU [$\Delta_{\%BW}$], –0.13 ± 0.82; DIME, –0.62 ± 0.91; *P* = .001), POST4M (SWU, –0.15 ± 0.98; DIME, –0.46 ± 0.64; *P* = .04), POST6M (SWU, –0.04 ± 0.96; DIME, –0.53 ± 0.83; *P* = .004), and POST8M (SWU, 0.38 ± 0.95; DIME, –0.11 ± 0.98; *P* = .003), but there was not a significant improvement in the DIME group between PRE and POST8M ($\Delta_{\%BW}$, –0.11 ± 0.98). No group differences in Δ LESS were observed.

Conclusion: The study findings demonstrated that an injury prevention program performed as a warm-up can reduce vertical ground-reaction forces compared with a standard warm-up but a maintenance program is likely necessary in order for continued benefit.

Clinical Relevance: Injury prevention programs may need to be performed constantly, or at least every sport season, in order for participants to maintain the protective effects against injury.

Keywords: biomechanics; neuromuscular training; military

A moderate level of evidence supports the use of exercise-based injury prevention programs to reduce the risk of anterior cruciate ligament (ACL) and other lower extremity injuries.[6,17,28] The intended effect of these programs is to reduce injury risk by improving biomechanical and neuromuscular characteristics. It is therefore logical to expect that the effect of these programs can be monitored by observing biomechanical and neuromuscular characteristics during functional tasks, such as movement patterns during jumping, landing, and cutting maneuvers. Previous research demonstrates significant improvements in vertical ground-reaction forces and movement patterns, such as knee flexion, knee valgus, and hip motion, immediately after completion of an exercise-based injury prevention program.[8,9,14,20]

An important gap in the knowledge base concerning exercise-based injury prevention programs is that the long-term effects of these programs are unknown. The limited available evidence suggests that there is no reason to assume that the protective effect is sustained for any appreciable period of time beyond the end of the program. Myklebust and Bahr[10] observed reduced injury rates after participants completed an injury prevention program, but

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these injury rates returned to pretraining levels within 1 year and actually increased within 3 years after participants discontinued the program. Immediate improvements in biomechanical and neuromuscular characteristics after completion of an injury prevention program suggest that function is improved, but do not indicate that new motor skills are learned or that the protective effects of the program are sustained over a period of months or years. It may be that these programs facilitate only temporary changes in the performance of functional tasks and that these changes degrade over time when the exercise program is no longer performed. If this is true, then it is important to maintain the program on an indefinite and ongoing basis to maximize the reduction in injury risk.

The indication that a new movement skill (such as a new jump-landing technique) has been fully learned should be permanent changes in the performance of the task.[27] Studies of motor skill learning are often based on retention tests whereby subjects are retested after a given time interval following completion of the training intervention. In 2 preliminary studies that evaluated the 3-month retention of movement-related changes after completion of an intervention to improve landing technique, investigators reported a decay in improvements of either ground-reaction forces or movement technique.[13,21] These findings suggest that immediate changes in biomechanical and neuromuscular factors after a lower extremity injury prevention program are not necessarily retained long-term.

The existing evidence does not indicate how often injury prevention programs must be performed to achieve long-term improvements in movement technique and reductions in injury risk. Understanding the trajectory of retention associated with lower-risk movement patterns after an exercise-based injury prevention intervention, and identifying optimal times for follow-up intervention, are critical gaps in the existing injury prevention literature. This knowledge is imperative to effectively implement injury prevention programs and improve injury prevention outcomes over time. Therefore, the primary purpose of this study was to evaluate the effects of a lower extremity injury prevention program (DIME: Dynamic Integrated Movement Enhancement), which was performed in a large-scale military setting, on movement technique and peak vertical ground-reaction forces over time (immediately before and after the program as well as 2, 4, 6, and 8 months after the program completion) compared with a standard warm-up (SWU) program. A secondary purpose was to determine whether the intervention reduced lower extremity injury rates after an injury prevention program. A priori, we hypothesized that the injury prevention program would modify landing technique but that these improvements would decline within 6 months of completion of the program. Our secondary hypothesis was that the DIME would reduce injury rates throughout the academic year.

METHODS

Design and Setting

We conducted a subgroup analysis of a cluster-randomized trial combined with a prospective time series panel to investigate the effectiveness (trial) and retention (panel) of an injury prevention exercise intervention at the United States Military Academy. The academy assigns incoming freshmen to 8 companies (a company is about 160 new students) for summer basic training (July-August) before the start of the start of academic year (late August). Individual-level randomization was not feasible in the military academy environment since all physical training is performed at the company level. The current study was a subgroup analysis from a larger, multiyear, cluster-randomized controlled trial with 3 study arms. A biostatistician assigned companies to study arms using a preassigned panel-based randomization plan. To maximize the use of study resources, 4 companies were assigned to the SWU, 2 to the DIME expert-supervised arm, and 2 to the DIME cadre-supervised arm. The same initial training was delivered to the individuals implementing the DIME program (cadre) for both DIME treatment arms (expert-supervised, cadre-supervised), but the cadre in the "expert-supervised DIME" received daily feedback about their implementation quality by trained experts of the DIME.

For the purposes of the current study, we chose to focus only on DIME expert-supervised group (2 companies, n = ~320 students) since the objective was to evaluate the effects of the DIME program over time and previous work demonstrated that this group experienced a 40% reduction in injury rates after completing the DIME.[2] Both the SWU and DIME programs were performed by their respective companies before morning physical training exercises approximately 2 or 3 times per week for 6 weeks. Movement technique during a standardized jump-landing task was assessed before (PRE) and after (POST) the 6-week intervention period, as well as 2 (POST2M), 4 (POST4M), 6 (POST6M), and 8 months (POST8M) after the intervention period (Figure 1). These follow-up assessments coincided with the end of each academic quarter (POST2M: first quarter, POST4M: second quarter, POST6M: third quarter, POST8M: fourth quarter).

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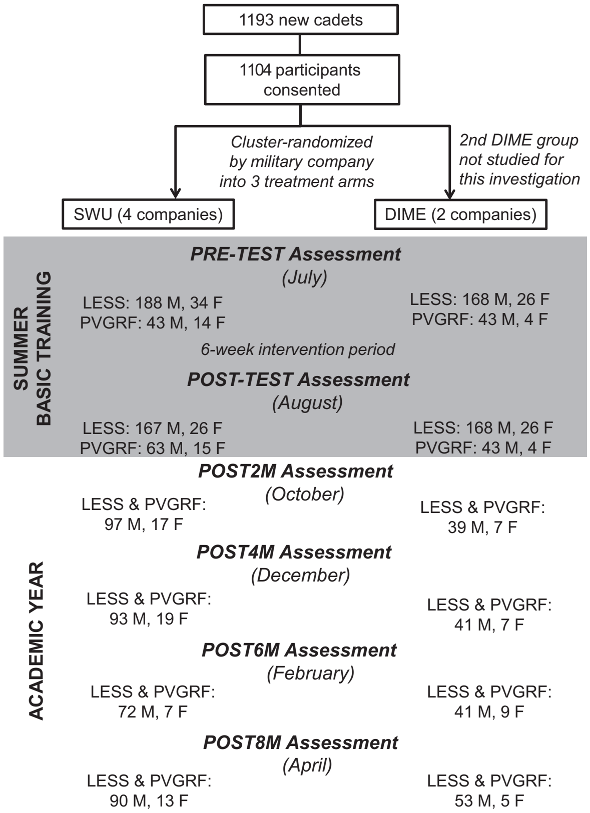

Figure 1. Flowchart of study procedures. DIME, Dynamic Integrated Movement Enhancement; F, female; LESS, Landing Error Scoring System; M, male; PRE, immediately before intervention; POST, immediately after intervention; POST2M, 2 months after intervention; POST4M, 4 months after intervention; POST6M, 6 months after intervention; POST8M, 8 months after intervention; PVGRF, peak vertical ground-reaction force; SWU, standard warm-up.

Participants

All participants were physically active students (age range, 17-22 years) who were incoming freshmen to the academy during the summer of 2012. All incoming freshmen were medically screened and deemed healthy according to the medical fitness standards for military service before enrollment in the study. Of the 1193 incoming freshmen in the summer of 2012, a total of 1104 (93%; 928 males, 176 females) volunteered to participate in this study, which was approved by multiple institutional review boards. All incoming freshmen completed the interventions, but only those who signed informed consent forms were included in the data analyses. Participants were free from any injury or illness that prohibited physical activity participation at the time of all test sessions. Participants were not blinded to their warm-up program.

Interventions

Both programs (DIME and SWU) are 10- to 12-minute warm-up programs that prepare the individual for physical activity. Both the SWU and the DIME programs consisted of dynamic flexibility, strengthening, agility, and plyometric exercises.[2] The SWU consisted of 10 standard exercises commonly used in the US Army before unit physical fitness training (Table 1). The DIME program places an increased emphasis on balance exercises in addition to the other exercises and was specifically designed to teach proper alignment during movements to avoid positions that increase lower extremity stress, such as knee valgus and limited sagittal plane motion (eg, knee flexion) (dimeinjuryprevention.weebly.com) (Table 2).

We used a "train the trainer" approach to implementation of the DIME program. Before the beginning of the summer physical training activities, physical education instructors received standardized, formal training (approximately 2 hours of focused training) in the DIME program by study staff. These physical education instructors then trained the cadre, or upperclassmen, at the military academy to implement the DIME. During the intervention, study staff monitored the DIME program performance to provide daily feedback and technique instruction to the instructors as well as evaluated injury prevention program compliance during the intervention period. After the 6-week summer basic training period concluded, study personnel did not intervene further during the following academic year. The physical education department at the academy was responsible for implementing the SWU program without involvement by study personnel but followed an identical procedure of using a "train the trainer" approach for training the cadre. Unfortunately, the implementers of both programs could not be blinded to intervention arm because they had prior experience with the SWU. There were no differences between study groups after the conclusion of the intervention period. All participants completed the same coursework and physical activity requirements.

Assessment of Movement Technique

All participants performed the PRE and POST movement assessment as part of their physical education requirement, but we graded only a random subsample of 400 participants due to study resources. The retention movement assessments (POST2M, POST4M, POST6M, POST8M) took place at a similar time point at the end of the academic quarter, with approximately 150 participants tested at each retention time point. An a priori power analysis indicated we would need at least 150 participants at all time periods to detect a significant effect. A repeated-measures design in which the same participants are tracked longitudinally over time was not feasible in the military setting. Instead, a panel design was used, in which independent groups were tested at each assessment point (ie, a panel of cross-sectional assessments over time). The panel design is logistically simpler to implement in the large military academy environment, eliminates bias due to loss to follow-up, maximizes power, and reduces the potential for a learning effect. This design is statistically efficient when within-subject correlations are low[3] and has been used in studies conducted in educational settings.[24]

TABLE 1
Standard Warm-up (SWU) Program

Exercise and Description
Bend and reach
Start position: Straddle stance with arms overhead, palms facing inward, fingers and thumbs extended and joined
Directions: Squat with the heels flat as the spine rounds forward to allow the straight arms to reach as far as possible between the legs. Return to the starting position.
Cadence: Slow
Repetitions: 5-10
Rear lunge
Start position: Straddle stance with hands on hips
Directions: Take an exaggerated step backward with the left leg, touching down with the ball of the foot. Return to the starting position. Repeat with the right leg.
Cadence: Slow
Repetitions: 5-10
High jumper
Start position: Forward-leaning stance, palms facing inward, fingers and thumbs extended and joined
Directions: Swing arms forward and jump a few inches. Swing arms backward and jump a few inches. Swing arms forward and vigorously overhead while jumping forcefully. Repeat, starting with swinging arms backward and jumping a few inches.
Cadence: Moderate
Repetitions: 5-10
Rower
Start position: Supine position, arms overhead, feet together and pointing upward; the chin is tucked, and the head is 1-2 inches above the ground; arms are held shoulder-width apart; palms face inward with fingers and thumbs extended and joined
Directions: Sit up while swinging arms forward and bending at the hips and knees. At the end of the motion, the arms will be parallel to the ground with palms facing inward. Return to the starting position.
Cadence: Slow
Repetitions: 5-10
Squat bender
Start position: Straddle stance with hands on hips
Directions: Squat while leaning slightly forward at the waist with the head up and extend the arms to the front, with arms parallel to the ground and palms facing inward. Return to the starting position. Bend forward and reach toward the ground with both arms extended and palms inward. Return to the starting position.
Cadence: Slow
Repetitions: 5-10
Windmill
Start position: Straddle stance with arms sideward, palms facing down, fingers and thumbs extended and joined
Directions: Bend the hips and knees while rotating to the left. Reach down and touch the outside of the left foot with the right hand and look toward the rear. The left arm is pulled rearward to maintain a straight line with the right arm. Return to the starting position. Repeat to the right.
Cadence: Slow
Repetitions: 5-10
Forward lunge
Start position: Straddle stance with hands on hips
Directions: Take a step forward with the left leg (left heel should be 3-6 inches forward of the right foot). Lunge forward, lowering the body, and allow the left knee to bend until the thigh is parallel to the ground. Lean slightly forward, keeping the back straight. Return to the starting position. Repeat with the right leg.
Cadence: Slow
Repetitions: 5-10
Prone row
Start position: Prone position with the arms overhead, palms down, fingers and thumbs extended and joined, 1-2 inches off the ground and toes pointed to the rear
Directions: Raise the head and chest slightly while lifting the arms and pulling them rearward. Hands make fists as they move toward the shoulders. Return to the starting position.
Cadence: Slow
Repetitions: 5-10
Bent-leg body twist
Start position: Supine position with the hips and knees bent to 90°, arms sideward and palms down; the knees and feet are together
Directions: Rotate the legs to the left while keeping the upper back and arms in place. Return to the starting position. Repeat to the right.
Cadence: Slow
Repetitions: 5-10
Push-up
Start position: Front leaning rest position
Directions: Bend the elbows, lowering the body until the upper arms are parallel with the ground. Return to the starting position.
Cadence: Moderate
Repetitions: 5-10

TABLE 2
Dynamic Integrated Movement Enhancement (DIME) Program

Exercise and Description
Double-leg squat
Start position: Feet shoulder-width apart, hands on hip bones
Directions: Squat down slowly, sending hips back as if sitting in a chair. Knees bend to 90°. Return to standing. Back stays flat throughout.
Cadence: Slow
Repetitions: 10
Squat jump
Start position: Squat position, arms in ready position in front
Directions: Jump up for maximum height and return to start position. Land softly toe to heel. Control the landing by bending at the hips, knees, and ankles.
Cadence: Moderate
Repetitions: 5, rest, 5
Forward lunge
Start position: Feet hip-width apart, hands on hips
Directions: Take a long step forward with right foot and slowly lower back knee toward ground. Push with front leg to return to standing. Alternate legs.
Cadence: Slow
Repetitions: 10
Side plank
Start position: Side lying on right side, elbow under shoulder, feet stacked
Directions: Lift hips, bringing them in a straight line with shoulder and feet. Brace abdominal and gluteal muscles. Hold 30 s, maintaining straight line head to spine.
Cadence: Stationary
Repetitions: 30 counts each side
Push-up
Start position: Front leaning rest
Directions: Maintain a flat back and brace the abdominal muscles. Lower body to ground, keeping elbows in. Push up to starting position.
Cadence: Moderate
Repetitions: 10
Single-leg reach
Start position: Standing on right leg with knee slightly bent
Directions: Extend arms by ears and tip forward at the hips, extending left leg to the rear. Keep hips level. Return to standing. Right leg stays slightly bent.
Cadence: Slow
Repetitions: 5 each side
Side hop to balance
Start position: Right foot, hands on hips.
Directions: Hop sideways, as if over a hurdle, and land on opposite foot. Bend at hips, knees, and ankles. Hold balance for 2 s. Hop back to other side and repeat.
Cadence: Very slow
Repetitions: 20
Ice skater
Start position: Right leg with knee bent, ready position
Directions: Hop sideways and land softly on the opposite foot, bending at hips, knees, and ankles. Hop immediately back to starting foot. Control the landing, maintain balance, and stay low.
Cadence: Moderate
Repetitions: 10
L hop
Start position: Right foot, hands on hips
Directions: Hop forward and land softly on right foot, bending at hips, knees, and ankles. Hop quickly back to start position. Hop to the right and back to start. Repeat 5 times. Repeat on the left leg in the opposite direction (forward, backward, left, back to start).
Cadence: Slow
Repetitions: 5 each side

All 6 movement assessments (PRE, POST, POST2M, POST4M, POST6M, POST8M) involved identical procedures, which required participants to perform 3 trials of the jump-landing task wearing military-issued shorts, T-shirt, and sneakers. Participants jumped forward from a 30-cm-high box a distance of half their body height, landed in a target landing area, and immediately jumped for maximal vertical height. Participants repeated a trial if they failed to jump with maximal effort, did not perform the jump with a fluid motion, jumped vertically instead of horizontally from the box, or did not land in the target area. A random subsample of participants during PRE and POST, as well as all

TABLE 3
Peak Vertical Ground-Reaction Forces (%BW): Change Scores for Each Assessment Point[a]

	SWU Group	DIME Group
POST vs PRE	–0.01 ± 0.84 (–0.19 to 0.18)	0.12 ± 0.90 (–0.17 to 0.40)
POST2M vs PRE[b]	–0.13 ± 0.82 (–0.29 to 0.03)	–0.62 ± 0.91 (–0.87 to –0.37)[c]
POST4M vs PRE[b]	–0.15 ± 0.98 (–0.32 to 0.02)	–0.46 ± 0.64 (–0.71 to –0.21)[c]
POST6M vs PRE[b]	–0.04 ± 0.96 (–0.25 to 0.17)	–0.53 ± 0.83 (–0.79 to –0.27)[c]
POST8M vs PRE[b]	0.38 ± 0.95 (0.18 to 0.57)	–0.11 ± 0.98 (–0.36 to 0.15)

[a]Values are reported as mean ± SD (range). %BW, percentage of body weight; DIME, Dynamic Integrated Movement Enhancement; PRE, immediately before intervention; POST, immediately after intervention; POST2M, 2 months after intervention; POST4M, 4 months after intervention; POST6M, 6 months after intervention; POST8M, 8 months after intervention; SWU, standard warm-up.
[b]Change in DIME significantly greater than change in SWU.
[c]Significant improvement determined by 95% CI of the change value ($P < .05$).

participants during POST2M, POST4M, POST6M, and POST8M assessments, landed in the target landing area with their dominant foot on a force plate (Model 4060-NC-2000; Bertec Corp). The dominant foot was defined as the limb used to kick a ball for maximal distance.

Two digital video cameras recorded the jump-landing task from the front and side of the participant. We used the Landing Error Scoring System (LESS) to quantify overall movement technique from these video images. The LESS is a clinical movement assessment tool that has been validated in the military academy population[18] and predicts subsequent injury risk in youth soccer players.[15] The total LESS score is based on a number of readily observable items of human movement during the jump-landing task. A higher LESS score indicates poor technique and higher risk of injury. An average LESS score was calculated from the total LESS scores from the 3 jump-landing trials. All raters were trained to score the LESS using standardized training procedures and were blinded to group assignment.

Motion Monitor software (Innovative Sports Training Inc) were used to collect ground-reaction force data from the force plate at a sampling frequency of 1440 Hz. These data were exported from Motion Monitor software to a customized software program (MatLab version 7; MathWorks). Peak vertical ground-reaction force (VGRF) was computed during the jump-landing task between initial ground contact (VGRF > 10 N) and toe-off (VGRF < 10 N) and was normalized to body mass (%BW).

Injury Outcomes

Lower extremity injury was operationally defined as a musculoskeletal injury that required the individual to seek treatment by a medical provider.[2] The military academy has a closed health care system, meaning that all cadets receive their health care at the academy. The health care providers at the academy were blinded to group assignment for this study. Injury tracking was performed using the Cadet Illness and Injury Tracking System (CIITS), which is an injury-surveillance database used at the academy. All cadets who become injured and seek medical care, miss training, or have limitations in training due to injury are entered into the CIITS database. Injury data were collected between the POST test session and the end of the academic year, which coincided with POST8M.

Data Analyses

We calculated change scores relative to the average baseline levels for each of the groups at each time point (POST-PRE, POST2M-PRE, POST4M-PRE, POST6M-PRE, POST8M-PRE) to ensure that preexisting group differences of PRE values did not confound the evaluation. We performed separate univariate analyses of variance (ANOVAs) with a Bonferroni correction to evaluate whether group differences (SWU, DIME) for each dependent variable (LESS average score, peak VGRF) existed at each of the 5 time points (POST, POST2M, POST4M, POST6M, POST8M). We assessed the data to ensure that they met all assumptions necessary for ANOVAs before analyses. We also evaluated the 95% confidence interval of each change score to determine whether significant improvements in the dependent variables were sustained within each group.

We calculated incidence proportions for both groups over the entire academic year and individual academic quarters (first, second, third, fourth). We examined the association between the intervention group (SWU vs DIME) and the cumulative incidence for lower extremity injury as well as the association between groups and incidence during each academic quarter using chi-square tests (or Fisher exact tests, as appropriate). Finally, we also examined the association between academic quarter and injury incidence for each group in the manner described previously. We calculated relative risk (RR) ratios and 95% CIs to compare the average risk between groups and between academic quarters. Participants who were injured during the summer were excluded from analyses because they were not fully exposed to the intervention programs. We used SPSS version 22.0 (IBM Corp) with an a priori alpha level of .05.

RESULTS

All companies completed the intervention period with an average of 14 exposures per company (range, 13-15). We observed a greater decrease in peak VGRF in the DIME group compared with the SWU group at all retention

TABLE 4
LESS Scores (Errors): Change Scores for Each Assessment Point[a]

	SWU Group	DIME Group
POST vs PRE	–0.55 ± 2.01 (–0.82 to –0.28)[b]	–0.32 ± 2.05 (–0.61 to –0.04)[b]
POST2M vs PRE	–0.59 ± 2.03 (–0.94 to –0.23)[b]	–0.01 ± 1.60 (–0.56 to 0.55)
POST4M vs PRE	–0.83 ± 1.87 (–1.16 to –0.50)[b]	–0.56 ± 1.53 (–1.07 to –0.06)[b]
POST6M vs PRE	–1.29 ± 1.83 (–1.70 to –0.87)[b]	–0.87 ± 1.95 (–1.39 to –0.34)[b]
POST8M vs PRE	–0.30 ± 1.98 (–0.68 to 0.08)	–0.39 ± 1.91 (–0.89 to 0.12)

[a]Values are reported as mean ± SD (range). DIME, Dynamic Integrated Movement Enhancement; LESS, Landing Error Scoring System; PRE, immediately before intervention; POST, immediately after intervention; POST2M, 2 months after intervention; POST4M, 4 months after intervention; POST6M, 6 months after intervention; POST8M, 8 months after intervention; SWU, standard warm-up.
[b]Significant change determined by 95% CI of the change value.

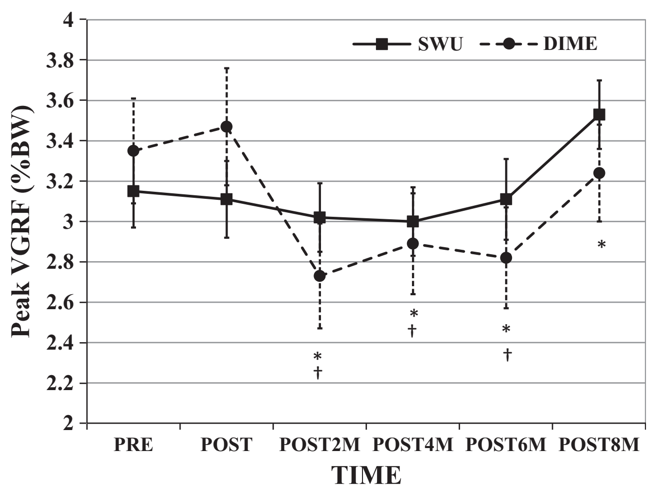

Figure 2. Peak vertical ground-reaction force (VGRF) over time. %BW, percentage of body weight; DIME, Dynamic Integrated Movement Enhancement; PRE, immediately before intervention; POST, immediately after intervention; POST2M, 2 months after intervention; POST4M, 4 months after intervention; POST6M, 6 months after intervention; POST8M, 8 months after intervention; SWU, standard warm-up. *Significant difference between groups; †significant change from PRE for DIME ($P < .05$).

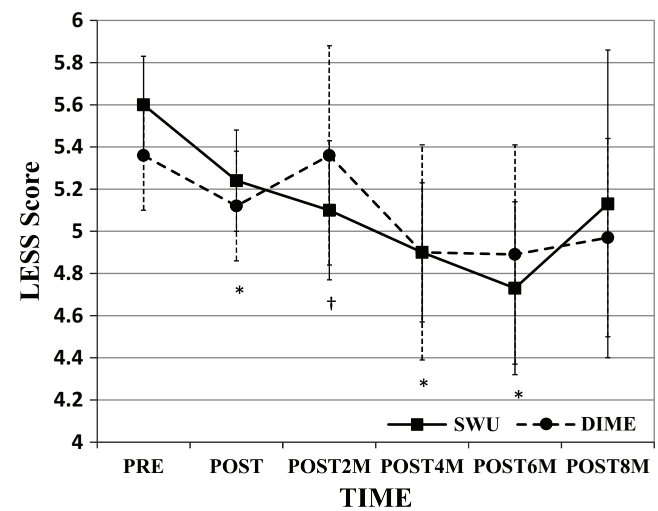

Figure 3. Landing Error Scoring System (LESS) scores over time. DIME, Dynamic Integrated Movement Enhancement; PRE, immediately before intervention; POST, immediately after intervention; POST2M, 2 months after intervention; POST4M, 4 months after intervention; POST6M, 6 months after intervention; POST8M, 8 months after intervention; SWU, standard warm-up. *Significant change from PRE for both groups; †significant change from PRE for SWU ($P < .05$).

time points: POST2M (P = .001), POST4M (P = .04), POST6M (P = .004), and POST8M (P = .003) (Table 3 and Figure 2). No other significant group differences were observed for peak VGRF. Within the DIME group itself, significant reductions in peak VGRF were sustained at POST2M, POST4M, and POST6M compared with PRE.

We did not observe any group differences in LESS change scores at any time point; however, the 95% confidence interval of the change scores demonstrated that both groups improved their LESS score at POST, POST4M, and POST6M compared with their PRE scores (Table 4 and Figure 3). The SWU group also sustained a change in LESS scores at POST2M relative to the PRE value.

Participants sustained 129 lower extremity injuries during the academic year after completion of the intervention period. Of these injuries, 90 occurred in participants in the SWU group (incidence proportion, 19.4%) and 39 in participants in the DIME group (incidence proportion, 17.0%). However, we did not observe any significant differences in the 1-year lower extremity injury rates between the 2 intervention groups (P = .44; RR = 0.88; 95% CI, 0.62-1.23). When we evaluated the injuries per academic quarter, which coincided with each retention assessment (ie, POST2M was at the end of the first quarter, POST4M was at the end of the second quarter, etc), no significant differences were found between groups during either quarter (Table 5). Participants in both groups had a significantly lower risk of sustaining a lower extremity injury during the second quarter, or 2 to 4 months after the intervention, compared with the fourth quarter, or 6 to 8 months after the intervention (DIME RR, 0.36; 95% CI, 0.13-0.98; P = .04; and SWU RR, 0.41; 95% CI, 0.21-0.80; P = .01).

TABLE 5
Injury Incidence Rates Per Academic Quarter[a]

	DIME Group	SWU Group	RR (95% CI)
POST2M	5.22	5.97	0.97 (0.50-1.90)
POST4M	2.17	2.87	0.84 (0.30-2.36)
POST6M	3.48	5.73	0.67 (0.31-1.48)
POST8M[b]	6.09	6.93	0.98 (0.53-1.81)

[a]DIME, Dynamic Integrated Movement Enhancement; POST2M, 2 months after intervention; POST4M, 4 months after intervention; POST6M, 6 months after intervention; POST8M, 8 months after intervention; RR, relative risk; SWU, standard warm-up.

[b]Significantly greater risk for the DIME group during the fourth quarter (POST8M) vs the second quarter (POST4M).

DISCUSSION

Evaluating both the immediate and long-term effects of an injury prevention program on movement patterns and landing forces provides insight into whether the program needs to be repeated or continually performed to have protective benefits. Our findings demonstrate that the DIME injury prevention program, which was performed as a warm-up activity in a large-scale setting, can reduce VGRF over time compared with a standard warm-up. The program, however, did not elicit greater improvements in overall movement technique, as measured by the LESS, than a standard warm-up. Regardless of warm-up program, all participants improved their movement technique after completing a 6-week period of intense basic training, suggesting that improved fitness and general movement exercises may contribute to our observed changes in movement technique.[22] These changes in global movement technique appear short-lived, however, as the changes in LESS and VGRF were no longer present 8 months after completion of the intervention period. Furthermore, lower extremity injury rates were highest for both groups 6 to 8 months after the intervention, even though we did not observe any group differences in injury rates. These findings support the use of injury prevention programs to improve landing technique but suggest that participants may need more than 6 weeks of training or may need to repeat the program every 6 months to reduce their injury risk in the long term.

Contrary to our original hypothesis, we did not observe immediate reductions in VGRF after participants completed the 6-week injury prevention program. However, decreases in landing forces were observed at subsequent assessments compared with the standard warm-up. We believe that 2 factors may be influencing these findings. First, the 6-week summer basic training period is considered one of the most demanding time periods of a student's life as it entails arduous physical training in addition to mental and emotional stress. Anecdotal observations demonstrate that these new students are visibly fatigued at the conclusion of the basic training period, which corresponded with the time of our POST assessment. Fatigue has been previously demonstrated to increase VGRF.[19] Therefore, participant fatigue may have prevented us from observing reductions in VGRF at POST but may not have been a factor 2 months after the conclusion of summer basic training.

The second possible explanation for the VGRF findings is that the cadets performed the follow-up, or retention, assessments near the end of a military movement physical education course each academic quarter. This course is designed to train the new students to control their bodies during military tasks including landings and involves gymnastics skills and obstacle course components. The feedback and instruction regarding movement control during this course are more general compared with the feedback and instruction provided during the DIME. Regardless, this continued training may have supplemented the DIME instruction and feedback, resulting in the reduced landing forces observed during the retention assessments. Sugimoto et al[25] concluded that the dosage of exposure to neuromuscular training has a direct relationship with injury rate reductions. Therefore, it is possible that the cadets assigned to the DIME program did not have enough exposures to result in changes during the intervention period but that continued exposure to movement training during the course helped facilitate the changes observed. While Owens et al[12] observed improved LESS scores and increased landing time in military cadets after completing this course, we do not believe that the military movement course alone resulted in the VGRF changes in the current study. Both groups (SWU, DIME) completed the military movement course at the same time, but the SWU did not result in the same reductions in VGRF.

While the DIME group demonstrated greater reductions in VGRF at 8 months after completion of the program compared with the SWU group, the change score within the DIME group suggests there was a decay in changes, as the confidence interval includes zero (indicating no significant change). Padua et al[13] observed that youth soccer athletes who completed a 9-month neuromuscular training program were able to maintain changes in landing technique for at least 3 months in contrast to athletes who only completed 3 months of training. These authors suggested that overlearning, or continued successful practice of a new motor skill, may have occurred during the longer training duration. The continued exposure to movement training may have resulted in significant landing technique changes for cadets who completed the DIME followed by the military movement course within the first 6 months after completing the intervention period. However, cadets who took the military movement course 6 months after the end of the intervention period may have been too far removed from the DIME exposure to facilitate improvements compared with their baseline performance. A limitation of this study is that we did not evaluate neuromuscular control at a time interval beyond the completion of the military movement course. Collectively, these findings suggest that a longer duration of general movement training, or some form of maintenance training, may be required to facilitate longer term or permanent decreases in landing forces.

We observed improved landing technique as measured by the LESS in both the SWU and DIME groups after completion of the intervention period despite the lack of immediate reductions in VGRF. Similar to the VGRF results, these changes did not remain 8 months after the intervention was completed, which supports previous research suggesting that improvements in landing technique are often transient and training may need to be continued for an extended period of time or that intermittent "booster" training may be needed to maximize effectiveness.[3,15] For example, the participants in Holm et al[5] investigation were able to maintain improvements in dynamic balance ability by performing a "maintenance phase" of the injury prevention program, or using it once a week, after an initial 5 to 7 weeks of performing the program several times per week. It is not possible to rule out that the changes in the LESS observed were due to a learning effect on the jump-landing task; however, we believe this is unlikely because of the demanding military environment where testing occurred, and the time series panel design helped remove this likelihood because one participant was unlikely to perform an assessment more than twice.

Theiss et al[26] failed to observe a relationship between LESS scores and fitness levels, as measured by the Army Physical Fitness Test (APFT), in military academy cadets. Therefore, it is unlikely that the changes observed in LESS scores for both groups are due to improved fitness alone, especially since a decay was observed for both groups in LESS scores by the end of the academic year. Physical fitness in cadets is continuously monitored at the academy through the APFT, so it is unlikely the cadets became less fit by the end of the academic year. Rather, we believe that the changes sustained are likely attributed to improving general physical literacy, or learning to control the body, which may have occurred from both the DIME and the SWU. Although the SWU program did not include balance exercises, specific instruction, or feedback emphasizing safe movement control (such as "bend the knees," "keep the knees over the toes," or "land softly"), the SWU program did require cadets to learn to control their bodies effectively to perform the set of required exercises. The deliberate movement task practice used to perform both the SWU and the DIME may have resulted in the observed motor skill transfer improvements to the jump-landing task.

We did not observe any statistically significant reductions in lower extremity injury rates between the SWU and DIME groups during the academic year. This finding agrees with previous research in this population, which failed to see a significant protective effect over a 1-year period[2]; however, the ability to detect a significant difference may be confounded in both studies by low statistical power for the injury outcomes of interest. The injury outcomes for the current study were a secondary purpose, as the study was a subgroup analysis of a larger multiyear investigation. Therefore, we did not power this study for the injury outcomes, which is a limitation. While not statistically significant, the DIME resulted in a 12% risk reduction compared with the SWU when all lower extremity injuries were considered. This result may still be meaningful, especially in a military academy environment where each new student is considered to be a large financial investment. While there were no group differences, we did detect higher injury rates 6 to 8 months after the intervention period for both groups, which together with the VGRF and LESS data reinforces that more exposures to the intervention or maintenance training may be required to have long-term protective benefits. Further research should evaluate multiple years of injury data to be sufficiently powered to make a definitive conclusion about the ability of an injury prevention program to reduce injury rates in a military population.

A "train the trainer" approach was used to implement the DIME program in this study, which may be an efficient and effective method for sport settings. Experts of the DIME program continued to provide implementation support to the program instructors throughout the intervention. These experts were athletic trainers and physical therapists proficient in the delivery of the DIME. While previous studies have also incorporated health care professionals in the implementation of injury prevention programs, this is not likely to be a feasible or sustainable solution. Previous work demonstrates that the "train the trainer" approach needs to be refined to improve delivery so continued support is not necessary to reduce injuries.[2] Myklebust et al[11] demonstrated a significant reduction in injury rates when physical therapists assisted with implementation of the intervention programs. However, not until after national campaigns and media attention demonstrated the consistent success of injury prevention programs in reducing injuries did injury rates sustain a consistent decline. Myklebust et al[11] and Padua et al[16] both stressed the need for effective implementation and dissemination that address the culture of injury prevention efforts to maximize adoption and compliance, as opposed to simply placing implementation in the hands of trained individuals, such as athletic trainers and physical therapists. Regardless, these results together suggest that maintenance implementation of injury prevention programs is likely necessary regardless of whether additional support is provided to implementation staff. Further implementation and dissemination research is needed to improve "train the trainer" efficiency and effectiveness.

A possible limitation of this study is that it was performed in a military academy population, which has an inherently high risk of injury[1] and high financial value to the institution and nation.[1] Injury prevention efforts are consequently paramount but can be challenging due to the nature of the environment. The DIME program required modification from previous preventive training programs that have been successful in reducing injury rates in sport populations. The DIME program needed to be performed in a stationary position to accommodate the large number of individuals performing the program at one time, in contrast to a more traditional "dynamic warm-up," which often includes running exercises. The DIME also had to be performed in less than 10 minutes, in contrast to most previously published programs that require 15 to 20 minutes.[4,7,23] The 10-minute limit may actually improve compliance with preventive training programs in sport, as coaches frequently report that time is a primary barrier to adoption of a preventive training program. However, a shorter dose of the program per day may require a longer duration (in terms of number of weeks) of program training to result in a similar overall dosage and protective effect. Our current findings may be limited by this relatively short program, which was performed only 15 times during the intervention period. Future research should evaluate a longer duration program in a military academy setting to determine whether a higher dose would elicit greater benefits and whether these results translate to sport environments.

CONCLUSION

We observed that the DIME injury prevention program reduces VGRF when supplemented with general movement exercises after the intervention concludes, but these changes do not appear to be maintained more than 6 months after the intervention. Both the DIME and the SWU modified overall movement technique, as measured by the LESS, but these changes along with reductions in injury rates and VGRF appear to dissipate 6 months after the intervention. VGRF may be more sensitive than global measures of movement technique, such as the LESS, in explaining the mechanistic changes responsible for injury prevention, but future research is warranted. The dosage of an injury prevention program, or neuromuscular training, appears to be vital to elicit changes in neuromuscular control. Although the protective effects of the DIME on injury rates were not conclusive, they do indicate that the program is not causing harm and with a larger sample size may result in statistically significant injury reductions. These findings further support that an injury prevention program may result in effects of short duration and that some form of a maintenance program is likely necessary for athletes to receive continued benefit.

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REFERENCES

1. Cameron KL, Owens BD. The burden and management of sports-related musculoskeletal injuries and conditions within the US military. *Clin Sports Med*. 2014;33(4):573-589.
2. Carow S, Haniuk E, Cameron K, et al. Risk of lower extremity injury in a military cadet population after a supervised injury-prevention program [published online August 12, 2014]. *J Athl Train*.
3. Feldman HA, McKinlay SM. Cohort versus cross-sectional design in large field trials: precision, sample size, and a unifying model. *Stat Med*. 1994;13(1):61-78.
4. Gilchrist J, Mandelbaum BR, Melancon H, et al. A randomized controlled trial to prevent noncontact anterior cruciate ligament injury in female collegiate soccer players. *Am J Sports Med*. 2008;36(8):1476-1483.
5. Holm I, Fosdahl MA, Friis A, Risberg MA, Myklebust G, Steen H. Effect of neuromuscular training on proprioception, balance, muscle strength, and lower limb function in female team handball players. *Clin J Sport Med*. 2004;14(2):88-94.
6. Hubscher M, Zech A, Pfeifer K, Hansel F, Vogt L, Banzer W. Neuromuscular training for sports injury prevention: a systematic review. *Med Sci Sports Exerc*. 2010;42(3):413-421.
7. LaBella CR, Huxford MR, Grissom J, Kim KY, Peng J, Christoffel KK. Effect of neuromuscular warm-up on injuries in female soccer and basketball athletes in urban public high schools: cluster randomized controlled trial. *Arch Pediatr Adolesc Med*. 2011;165(11):1033-1040.
8. Lim BO, Lee YS, Kim JG, An KO, Yoo J, Kwon YH. Effects of sports injury prevention training on the biomechanical risk factors of anterior cruciate ligament injury in high school female basketball players. *Am J Sports Med*. 2009;37(9):1728-1734.
9. Myer GD, Ford KR, McLean SG, Hewett TE. The effects of plyometric versus dynamic stabilization and balance training on lower extremity biomechanics. *Am J Sports Med*. 2006;34(3):445-455.
10. Mykelbust G, Bahr R. Alarming increase in ACL injuries among female team handball players after the end of successful intervention study: a 2 year follow up. *Br J Sports Med*. 2005;39:382-383.
11. Myklebust G, Skjolberg A, Bahr R. ACL injury incidence in female handball 10 years after the Norwegian ACL prevention study: important lessons learned. *Br J Sports Med*. 2013;47(8):476-479.
12. Owens BD, Cameron KL, Duffey ML, et al. Military movement training program improves jump-landing mechanics associated with anterior cruciate ligament injury risk. *J Surg Orthop Adv*. 2013;22(1):66-70.
13. Padua D, DiStefano L, Marshall S, Beutler A, de la Motte S, DiStefano M. Retention of movement pattern changes following a lower extremity injury prevention program is affected by program duration. *Am J Sports Med*. 2012;40(2):300-306.
14. Padua DA, DiStefano LJ. Sagittal plane knee biomechanics and vertical ground reaction forces are modified following ACL injury prevention programs: a systematic review. *Sports Health*. 2009;1(2):165-173.
15. Padua DA, DiStefano LJ, Beutler AI, de la Motte SJ, DiStefano MJ, Marshall SW. The Landing Error Scoring System as a screening tool for an anterior cruciate ligament injury-prevention program in elite-youth soccer athletes. *J Athl Train*. 2015;50(6):589-595.
16. Padua DA, Frank B, Donaldson A, et al. Seven steps for developing and implementing a preventive training program: lessons learned from JUMP-ACL and beyond. *Clin Sports Med*. 2014;33(4):615-632.
17. Padua DA, Marshall SW. Evidence supporting ACL injury prevention exercise programs: a review of the literature. *Athl Ther Today*. 2006;11:11-25.
18. Padua DA, Marshall SW, Boling MC, Thigpen CA, Garrett WE Jr, Beutler AI. The Landing Error Scoring System (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: the JUMP-ACL study. *Am J Sports Med*. 2009;37(10):1996-2002.
19. Pappas E, Sheikhzadeh A, Hagins M, Nordin M. The effect of gender and fatigue on the biomechanics of bilateral landings from a jump: peak values. *J Sports Sci Med*. 2007;6(1):77-84.
20. Pollard CD, Sigward SM, Ota S, Langford K, Powers CM. The influence of in-season injury prevention training on lower-extremity kinematics during landing in female soccer players. *Clin J Sport Med*. 2006;16(3):223-227.
21. Prapavessis H, McNair PJ, Anderson K, Hohepa M. Decreasing landing forces in children: the effect of instructions. *J Orthop Sports Phys Ther*. 2003;33(4):204-207.
22. Scott SA, Simon JE, Van Der Pol B, Docherty CL. Risk factors for sustaining a lower extremity injury in an Army Reserve Officer Training Corps Cadet Population. *Mil Med*. 2015;180(8):910-916.
23. Steffen K, Myklebust G, Olsen OE, Holme I, Bahr R. Preventing injuries in female youth football—a cluster-randomized controlled trial. *Scand J Med Sci Sports*. 2008;18(5):605-614.
24. Stevens J, Murray DM, Catellier DJ, et al. Design of the Trial of Activity in Adolescent Girls (TAAG). *Contemp Clin Trials*. 2005;26(2):223-233.
25. Sugimoto D, Myer GD, Bush HM, Klugman MF, Medina McKeon JM, Hewett TE. Compliance with neuromuscular training and anterior cruciate ligament injury risk reduction in female athletes: a meta-analysis. *J Athl Train*. 2012;47(6):714-723.
26. Theiss JL, Gerber JT, Cameron K, et al. Jump-landing differences between varsity, club, and intramural athletes: the Jump-ACL study. *J Strength Cond Res*. 2014;28(4):1164-1171.
27. Wulf G, Shea C, Lewthwaite R. Motor skill learning and performance: a review of influential factors. *Med Educ*. 2010;44(1):75-84.
28. Yoo JH, Lim BO, Ha M, et al. A meta-analysis of the effect of neuromuscular training on the prevention of the anterior cruciate ligament injury in female athletes. *Knee Surg Sports Traumatol Arthrosc*. 2010;18(6):824-830.