

A School-Based Neuromuscular Training Program and Sport-Related Injury Incidence: A Prospective Randomized Controlled Clinical Trial

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Context: An estimated 40 million school-aged children (age range = 5–18 years) participate annually in sports in the United States, generating approximately 4 million sport-related injuries and requiring 2.6 million emergency department visits at a cost of nearly \$2 billion.

Objective: To determine the effects of a school-based neuromuscular training (NMT) program on sport-related injury incidence across 3 sports at the high school and middle school levels, focusing particularly on knee and ankle injuries.

Design: Randomized controlled clinical trial.

Setting: A total of 5 middle schools and 4 high schools in a single-county public school district.

Patients or Other Participants: A total of 474 girls (222 middle school, 252 high school; age = 14.0 ± 1.7 years, height = 161.0 ± 8.1 cm, mass = 55.4 ± 12.2 kg) were cluster randomized to an NMT (CORE; $n = 259$ athletes) or sham (SHAM; $n = 215$ athletes) intervention group by team within each sport (basketball, soccer, and volleyball).

Intervention(s): The CORE intervention consisted of exercises focused on the trunk and lower extremity, whereas the SHAM protocol consisted of resisted running using elastic bands. Each intervention was implemented at the start of the season and continued until the last competition. An athletic trainer evaluated athletes weekly for sport-related injuries. The coach recorded each *athlete-exposure* (AE), which was defined as 1 athlete participating in 1 coach-directed session (game or practice).

Main Outcome Measure(s): Injury rates were calculated overall, by sport, and by competition level. We also calculated rates of specific knee and ankle injuries. A mixed-model approach was used to account for multiple injuries per athlete.

Results: Overall, the CORE group reported 107 injuries (rate = 5.34 injuries/1000 AEs), and the SHAM group reported 134 injuries (rate = 8.54 injuries/1000 AEs; $F_{1,578} = 18.65$, $P < .001$). Basketball (rate = 4.99 injuries/1000 AEs) and volleyball (rate = 5.74 injuries/1000 AEs) athletes in the CORE group demonstrated lower injury incidences than basketball (rate = 7.72 injuries/1000 AEs) and volleyball (rate = 11.63 injuries/1000 AEs; $F_{1,275} = 9.46$, $P = .002$ and $F_{1,149} = 11.36$, $P = .001$, respectively) athletes in the SHAM group. The CORE intervention appeared to have a greater protective effect on knee injuries at the middle school level (knee-injury incidence rate = 4.16 injuries/1000 AEs) than the SHAM intervention (knee-injury incidence rate = 7.04 injuries/1000 AEs; $F_{1,261} = 5.36$, $P = .02$). We did not observe differences between groups for ankle injuries ($F_{1,578} = 1.02$, $P = .31$).

Conclusions: Participation in an NMT intervention program resulted in a reduced injury incidence relative to participation in a SHAM intervention. This protective benefit of NMT was demonstrated at both the high school and middle school levels.

Key Words: epidemiology, middle school athletes, high school athletes, sport injuries, injury rates

Key Points

- Young female athletes participating in a neuromuscular training (NMT) program had a reduced injury incidence compared with athletes participating in a sham intervention.
- Implementing the NMT program for female middle and high school athletes prevented injuries in basketball and volleyball players over an athletic season.
- The protective effect of the NMT program was most pronounced for knee injuries in middle school volleyball athletes.

An estimated 40 million school-aged children (age range = 5–18 years) participate annually in sports in the United States, which is a 21% increase in the past decade.^{1–3} Researchers^{1,3–6} have estimated that these athletes will sustain approximately 4 million sport-related injuries annually, requiring 2.6 million emergency department visits at a cost of nearly \$2 billion. These data indicate that targeted injury-prevention interventions are needed to reduce the physical and economic burden of sport-related injuries in young populations.

Among the many benefits for both sexes of participating in athletics are an improved sense of wellbeing, better cardiorespiratory function, enhanced physical fitness, and a positive body image; however, an inherent risk of sport-related injury exists.^{6–9} Up to a 10-fold increased risk of injury has been shown in female athletes compared with male athletes, particularly for anterior cruciate ligament (ACL) sprains and patellofemoral pain.^{10–13} Ankle injuries account for approximately 40% of high school injuries in female athletes.^{14,15} Given the high prevalence of injury to these 2 body regions, interventions should focus on overall injury reduction, as well as lowering the specific risks of ankle and knee injuries. In injury-surveillance research, investigators¹⁶ have reported injury rates of 4.4, 5.3, and 1.7 per 1000 athlete-exposures (AEs) in high school-aged female athletes for basketball, soccer, and volleyball, respectively. In a youth soccer-specific epidemiologic study, Schiff et al¹⁷ found that female athletes had an acute injury rate of 4.7 per 1000 AEs. Barber Foss et al¹⁸ observed that middle school female athletes had a 50% risk of injury during athletic participation.

Given these increased rates and risks of injury, injury-prevention interventions are needed to target high-risk female adolescent athletes. Therefore, the purpose of our study was to conduct a prospective randomized controlled clinical trial to evaluate the effects of a school-based neuromuscular training (NMT) program on sport-related injury incidence across 3 different sports at the high school and middle school levels.

METHODS

Participants

Female basketball (n = 247), soccer (n = 142), and volleyball (n = 137) players from a single-county public school district in Kentucky comprising 5 middle schools and 4 high schools participated in this investigation. The 526 roster players consisted of 474 individual athletes (age = 14.0 ± 1.7 years, height = 161.0 ± 8.1 cm, mass = 55.4 ± 12.2 kg), some of whom played more than 1 sport. Of these 474 athletes, 222 athletes participated at the middle school level, and 252 athletes participated at the high school level, and they could participate in multiple sports. A total of 177 athletes incurred 241 independent injuries. In this district, soccer and volleyball were fall sports, and basketball was a winter sport. Injuries were recorded for the specific season in which they occurred. All participants and their parents or guardians provided written informed assent and consent, respectively, and the Cincinnati Children's Hospital Institutional Review Board approved the study.

Table 1. Examples of Core Exercises Completed Preseason

Session 1 Exercise	Performance	Illustration
Lateral jump and hold	8 repetitions on each lower limb	Figure 1A
Step hold	8 repetitions on each lower limb	Figure 1B
BOSU ^a (round) swimmers	2 sets of 10 repetitions	Figure 1C
BOSU ^a (round) double-knee hold	Two 20-s repetitions	Figure 1D
Single-legged lateral AIREX ^b hop-hold	4 repetitions on each lower limb	Figure 1E
Single tuck jump with soft landing	2 sets of 10 repetitions	Figure 1F
Front lunges	10 repetitions on each lower limb	Figure 1G
Lunge jumps	10-s repetition on each lower limb	Figure 1H
BOSU ^a (flat) double-legged pelvic bridges	2 sets of 10 repetitions	Figure 1I
Single-legged 90° hop hold	8 repetitions on each lower limb	Figure 1J
BOSU ^a (round) lateral crunch	10 repetitions on each lower limb	Figure 1K
Box double crunch	2 sets of 15 repetitions	Figure 1L
Swiss ball back hyperextensions	2 sets of 15 repetitions	Figure 1M

^a BOSU, Ashland, OH.

^b Airex AG, Sins, Switzerland.

Procedures

We cluster randomized 259 athletes (103 middle school, 156 high school) to an NMT (CORE) intervention and 215 athletes (119 middle school, 96 high school) to a sham (SHAM) intervention group by team within each sport. The CORE intervention consisted of exercises focused on the trunk and lower extremity, and the SHAM protocol consisted of resisted running using elastic bands.^{19,20} Figure 1 and Table 1 depict examples of exercises completed in the preseason; Figure 2 and Table 2, in-season. Detailed descriptions of these interventions have been published.^{19,21} Each intervention was implemented at the start of the season and continued until the last competition. From the first day of team practice until the first competition, teams were instructed to perform the training for 20 to 25 minutes, 3 times per week. When competition started, teams were instructed to perform a reduced-volume training protocol

Table 2. Examples of Core Exercises Completed In-Season

Session 19 Exercise	Performance	Illustration
Step hold	8 repetitions on each lower limb	Figure 2A
BOSU ^a (flat) double-legged pelvic bridges	2 sets of 8 repetitions	Figure 2B
Single-legged 90° hop hold	10 repetitions on each lower limb	Figure 2C
Single-legged Romanian dead lift	1 set on each lower limb	Figure 2D
Unanticipated hop to stabilization (level 1)	Three 5-s repetitions on each lower limb	Figure 2E
Hop to stabilization and reach (level 1)	3 repetitions on each lower limb	Figure 2F
Single tuck jump with soft landing	Two 10-s repetitions	Figure 2G

^a BOSU, Ashland, OH.



Figure 1. Examples of neuromuscular-training intervention exercises completed preseason. A, Lateral jump and hold; B, step hold; C, BOSU (round; Ashland, OH) swimmers; D, BOSU (round) double-knee hold; E, single-legged lateral AIREX (Airex AG, Sins, Switzerland) hop-hold; F, single tuck jump with soft landing; G, front lunges; H, lunge jumps; I, BOSU (flat) double-legged pelvic bridges; J, single-legged 90° hop hold; K, BOSU (round) lateral crunch; L, box double crunch; M, Swiss ball back hyperextensions.

for 10 to 15 minutes, 2 times per week, until the end of the competitive season.

Athletes were evaluated by an athletic trainer (AT) weekly during each sport season for sport-related injuries. *Injury* was operationally defined as (1) any injury causing cessation of participation in the current session, (2) any injury that caused cessation of participation on the day after the day of onset, (3) any fracture, (4) any dental injury, and (5) any mild brain injury, regardless of time missed from participation.^{16,22}

Knee and ankle injuries included both sprains and strains. Knee injuries also included plica, fat pad, bursa, and patellofemoral pain conditions. Athlete-exposures were recorded weekly by a coach and verified by the study coordinator (K.B.F.). An *AE* (ie, opportunity for injury) was defined as 1 athlete participating in 1 coach-directed session (game or practice).^{16,22} Exposure data were submitted by the coach via a custom-built Sports Injury Surveillance System (Cincinnati Children's Hospital Medical Center Division of

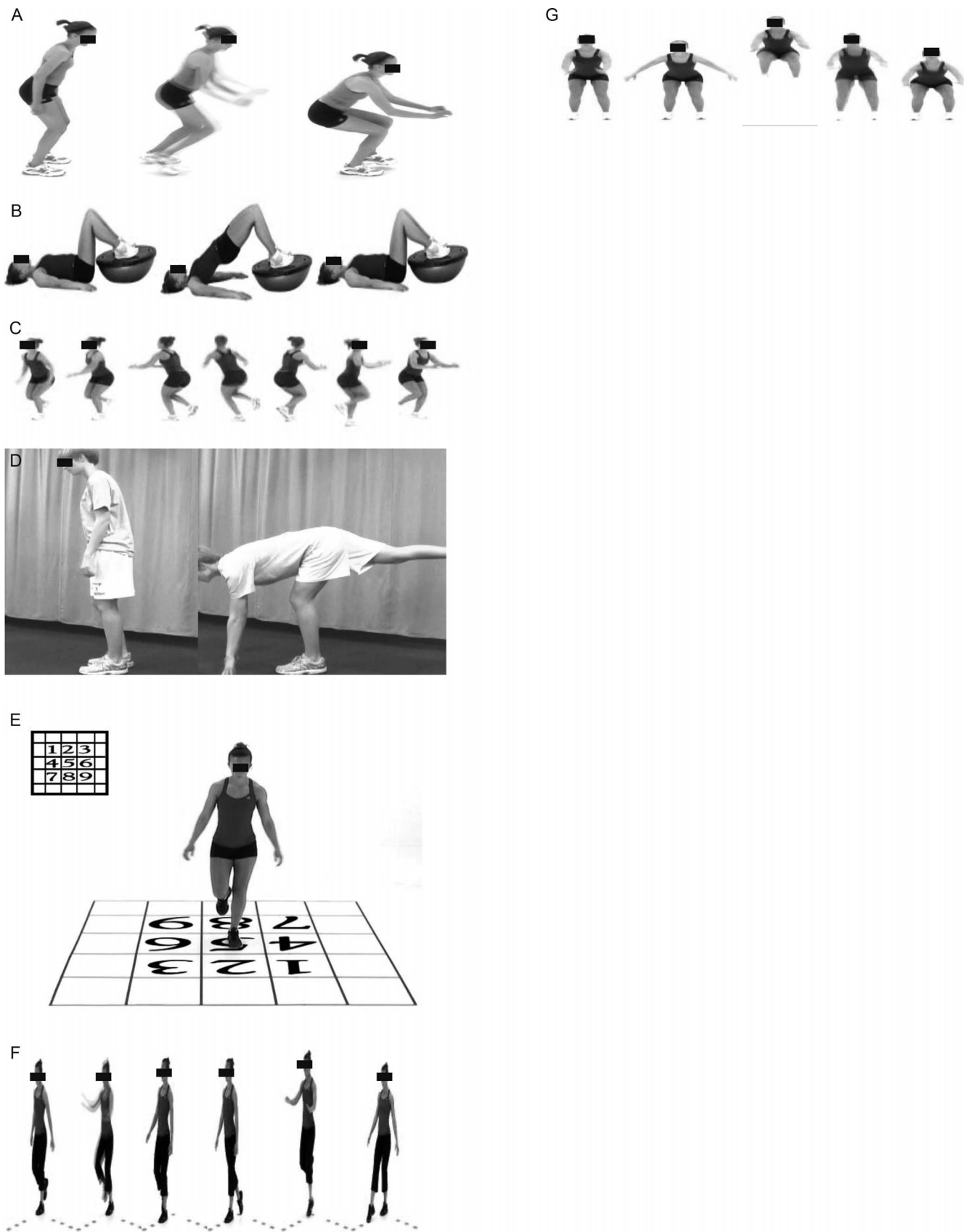


Figure 2. Examples of neuromuscular-training intervention exercises completed while teams were in-season. A, Step hold; B, BOSU (flat; Ashland, OH) double-legged pelvic bridges; C, single-legged 90° hop hold; D, single-legged Romanian dead lift; E, unanticipated hop to stabilization (level 1); F, hop to stabilization and reach (level 1); G, single tuck jump with soft landing.

Table 3. Examination of All Injuries: Rates by Exposure

Sport	CORE Intervention			SHAM Intervention			F Value	P Value	Absolute Risk Reduction Rate per 1000 AEs (95% CI)
	No. of Injuries	No. of Exposures	Rate per 1000 AEs (Standard Error) ^a	No. of Injuries	No. of Exposures	Rate per 1000 AEs (Standard Error) ^a			
Overall	107	22 906	5.34 (0.51)	134	19 875	8.54 (0.54)	18.65	<.001 ^b	3.20 (1.71, 4.69)
High school	65	15 389	4.81 (0.52)	66	11 998	6.65 (0.62)	5.26	.02 ^b	1.84 (0.25, 3.43)
Middle school	42	7517	6.00 (0.97)	68	7877	10.66 (0.88)	12.72	<.001 ^b	4.66 (1.98, 7.34)
Basketball	51	11 106	4.99 (0.63)	73	10 769	7.72 (0.63)	9.46	.002 ^b	2.73 (0.92, 4.54)
High school	17	4917	3.32 (0.72)	23	3864	7.21 (0.89)	11.51	.001 ^b	3.89 (1.44, 6.34)
Middle school	34	6189	6.14 (0.90)	50	6905	7.90 (0.80)	2.15	.14	1.76 (−0.67, 4.19)
Soccer	25	6060	5.47 (1.10)	31	5409	7.64 (1.12)	1.92	.17	2.17 (−1.01, 5.35)
High school	22	5758	4.80 (0.85)	23	4813	5.68 (0.93)	0.48	.49	0.88 (−1.67, 3.43)
Middle school	3	302	9.93 (5.10)	8	596	13.42 (3.70)	0.31	.58	3.49 (−3.20, 10.18)
Volleyball	31	5740	5.74 (1.09)	30	3697	11.63 (1.36)	11.36	.001 ^b	5.89 (2.41, 9.37)
High school	26	4714	5.94 (1.00)	20	3321	7.40 (1.26)	0.82	.37	1.46 (−1.74, 4.66)
Middle school	5	1026	4.03 (2.29)	10	376	20.70 (2.43)	24.98	<.001 ^b	16.67 (8.40, 24.94)

Abbreviations: AEs, athlete-exposures; CI, confidence interval; CORE, exercises focused on the trunk and lower extremity; SHAM, resisted running with elastic bands.

^a Athlete-exposures were calculated by multiplying the number of team exposures by the number of athletes on the team.

^b Indicates difference ($P < .05$).

Bioinformatics, Cincinnati, OH). Injuries were recorded by the AT in the Sports Injury Monitoring System (Flan Tech Computer Services, Iowa City, IA).

Statistical Analyses

Data were analyzed by intervention for each reported injury. Injury rates were estimated overall, by sport, and by competition level. Specific analyses were conducted on knee and ankle injuries. Statistical analyses were performed in SAS software (version 9.3; SAS Institute, Cary, NC). We used χ^2 or Fisher exact tests to examine differences in athletes with 1 or more injuries and a mixed-model approach to compare injury rates between groups to account for multiple injuries per athlete. The α level was set at .05.

RESULTS

Training was implemented in team (basketball, soccer, and volleyball) clusters, which resulted in greater than 95% compliance with data monitoring. Total exposures collected for the teams are presented in Table 3. A total of 80 (31%) of the 259 CORE group athletes and 97 (45%) of the 215 SHAM group athletes had at least 1 injury ($\chi^2_1 = 10.16, P = .001$). The CORE group sustained 107 injuries (rate = 5.34 injuries/1000 AEs), and the SHAM group sustained 134 injuries (rate = 8.54 injuries/1000 AEs; $F_{1,578} = 18.65, P < .001$; Table 3). We observed a 1.6-times reduction in injury rate between the CORE and SHAM intervention groups for all injuries over the investigation period, with an absolute risk-reduction rate of 3.20 (95% confidence interval [CI] = 1.71, 4.69) per 1000 AEs. The latter translates into a reduction of 128 injuries in our population alone. The basketball (rate = 4.99 injuries/1000 AEs) and volleyball (rate = 5.74 injuries/1000 AEs) athletes in the CORE group had lower injury incidences than the basketball (rate = 7.72 injuries/1000 AEs) and volleyball (rate = 11.63 injuries/1000 AEs) athletes in the SHAM group ($F_{1,275} = 9.46, P = .002$ and $F_{1,149} = 11.36, P = .001$, respectively). We did not observe a reduction for the soccer athletes in the CORE

(rate = 5.47 injuries/1000 AEs) or SHAM (rate = 7.64 injuries/1000 AEs; $F_{1,150} = 1.92, P = .17$) group.

Effect on Level

At the high school level, 48 (31%) of 156 CORE group athletes and 44 (46%) of 96 SHAM group athletes sustained at least 1 injury ($\chi^2_1 = 5.82, P = .02$). At the middle school level, 32 (31%) of the 103 CORE group athletes and 53 (45%) of the 119 SHAM group athletes had at least 1 injury ($\chi^2_1 = 4.24, P = .04$).

Effect on Basketball Injuries

The CORE group had a reduction in injuries ($\chi^2_1 = 5.51, P = .02$). A total of 39 of 126 (31%) CORE group athletes and 55 of 121 (45%) SHAM group athletes sustained at least 1 injury. This reduction in injury incidence was most pronounced at the high school level, with only 14 of 53 (26%) CORE group athletes versus 17 of 30 (57%) SHAM group athletes incurring an injury ($\chi^2_1 = 7.49, P = .006$). At the middle school level, the number of injured athletes in the CORE group (25 of 73 [34%] athletes) and the SHAM group (38 of 91 [42%] athletes) was not different ($\chi^2_1 = 0.97, P = .33$).

Effect on Soccer Injuries

Of the 142 soccer athletes in the study, 74 were in the CORE group, and 68 were in the SHAM group. They comprised 116 high school and 26 middle school students. Soccer was not a school-sponsored sport in the middle school setting, which accounted for the small sample size. In the high school setting, the CORE group had 22 injuries (30%), and the SHAM group had 23 injuries (34%; $\chi^2_1 = 0.50, P = .49$). We did not observe a difference between groups in injury reduction for soccer ($P = .17$).

Effect on Volleyball Injuries

Of the 137 volleyball athletes, 24 of 85 (28%) CORE group athletes and 23 of 52 (44%) SHAM group athletes

Table 4. Examination of Knee and Patellar Injuries Only: Rates by Exposure

Sport	CORE Intervention			SHAM Intervention			F Value	P Value	Absolute Risk Reduction Rate per 1000 AEs (95% CI)
	No. of Injuries	No. of Exposures	Rate per 1000 AEs (Standard Error) ^a	No. of Injuries	No. of Exposures	Rate per 1000 AEs (Standard Error) ^a			
Overall	60	22 906	3.12 (0.46)	72	19 875	4.97 (0.49)	7.57	.006 ^b	1.59 (1.14, 2.34)
High school	32	15 389	2.37 (0.43)	32	11 998	3.37 (0.51)	2.26	.13	1.42 (0.89, 2.38)
Middle school	28	7517	4.16 (0.92)	40	7877	7.04 (0.83)	5.36	.02 ^b	1.92 (1.07, 3.14)
Basketball	35	11 106	3.55 (0.56)	36	10 769	3.80 (0.56)	0.10	.75	1.07 (0.72, 1.65)
High school	12	4917	2.36 (0.63)	10	3864	2.93 (0.79)	0.32	.57	1.24 (0.49, 3.14)
Middle school	23	6189	4.35 (0.81)	26	6905	4.10 (0.72)	0.05	.82	0.94 (0.55, 1.64)
Soccer	11	6060	2.74 (0.96)	15	5409	4.19 (1.00)	1.12	.29	1.53 (0.64, 5.84)
High school	8	5758	1.66 (0.59)	9	4813	2.20 (0.64)	0.37	.54	1.32 (0.44, 5.70)
Middle school	3	302	9.93 (4.90)	6	596	10.07 (3.55)	0.00	.98	1.01 (inestimable)
Volleyball	14	5740	2.80 (1.00)	21	3697	8.70 (1.25)	13.59	<.001 ^b	3.12 (1.62, 11.61)
High school	12	4714	3.01 (0.89)	13	3321	5.15 (1.12)	2.21	.14	1.71 (0.80, 4.64)
Middle school	2	1026	1.31 (2.17)	8	376	17.70 (2.31)	26.78	<.001 ^b	13.51 (inestimable)

Abbreviations: AEs, athlete-exposures; CI, confidence interval; CORE, exercises focused on the trunk and lower extremity; SHAM, resisted running with elastic bands.

^a Athlete-exposures were calculated by multiplying the number of team exposures by the number of athletes on the team.

^b Indicates difference ($P < .05$).

sustained at least 1 injury ($\chi^2_1 = 3.66$, $P = .056$). Whereas the reduction in basketball injuries was more prominent at the high school level, the opposite was true of volleyball; 5 of the 25 (20%) middle school volleyball players in the CORE group versus 13 of the 20 (65%) players in the SHAM group were injured ($\chi^2_1 = 9.38$, $P = .002$).

Effect on Knee Injuries Only

The effect of the CORE intervention on knee injuries is presented in Table 4. The CORE intervention appeared to have the greatest protective effect on knee injuries at the middle school level, with a knee-injury incidence rate of 4.16 per 1000 AEs compared with 7.04 per 1000 AEs in the SHAM group ($F_{1,261} = 5.36$, $P = .02$). Volleyball was the only individual sport with a reduction in overall injuries (rate = 2.80 versus 8.70 injuries/1000 AEs; $F_{1,149} = 13.59$, $P < .001$) and an even greater reduction at the middle

school level (rate = 1.31 versus 17.70 injuries/1000 AEs; $F_{1,47} = 26.78$, $P < .001$) for the CORE versus SHAM group. Of the 3 ACL injuries reported, 2 affected girls were assigned to the SHAM group.

Effect on Ankle Injuries Only

We did not observe differences for ankle injuries between the CORE and SHAM groups overall, by level, or by sport (Table 5).

DISCUSSION

The purpose of our study was to prospectively evaluate injury incidence in middle and high school athletes randomly assigned to an NMT (CORE) intervention group compared with that in a SHAM group across the sports of basketball, soccer, and volleyball. We observed a difference in injury rates between the 2 groups, indicating that

Table 5. Examination of Ankle Injuries Only: Rates by Exposure

Sport	CORE Intervention			SHAM Intervention			F Value	P Value	Absolute Risk Reduction Rate per 1000 AEs (95% CI)
	No. of Injuries	No. of Exposures	Rate per 1000 AEs (Standard Error) ^a	No. of Injuries	No. of Exposures	Rate per 1000 AEs (Standard Error) ^a			
Overall	27	22 906	1.26 (0.26)	30	19 875	1.63 (0.27)	1.02	.31	1.29 (0.76, 2.34)
High school	17	15 389	1.20 (0.31)	18	11 998	1.75 (0.36)	1.34	.25	1.46 (0.74, 3.25)
Middle school	10	7517	1.26 (0.43)	12	7877	1.41 (0.38)	0.06	.80	1.12 (0.42, 3.99)
Basketball	12	11 106	1.07 (0.36)	17	10 769	1.77 (0.36)	1.87	.17	1.65 (0.78, 5.57)
High school	5	4917	0.96 (0.50)	6	3864	2.04 (0.63)	1.82	.18	2.12 (inestimable)
Middle school	7	6189	1.56 (0.49)	11	6905	1.67 (0.44)	0.62	.43	1.07 (0.41, 3.45)
Soccer	6	6060	1.18 (0.55)	9	5409	1.85 (0.56)	0.72	.40	1.57 (inestimable)
High school	6	5758	1.36 (0.56)	8	4813	1.91 (0.62)	0.44	.51	1.40 (0.36, 14.79)
Middle school	0	302	0.00 (1.89)	1	596	1.68 (1.37)	0.52	.48	Inestimable
Volleyball	9	5740	1.59 (0.48)	4	3697	1.03 (0.60)	0.53	.47	0.65 (-0.19, 2.49)
High school	6	4714	1.24 (0.51)	4	3321	1.32 (0.64)	0.01	.92	1.06 (inestimable)
Middle school	3	1026	2.09 (0.86)	0	376	0.00 (0.91)	2.79	.10	Inestimable

Abbreviations: AEs, athlete-exposures; CI, confidence interval; CORE, exercises focused on the trunk and lower extremity; SHAM, resisted running with elastic bands.

^a Athlete-exposures were calculated by multiplying the number of team exposures by the number of athletes on the team.

the CORE intervention program offered protection against injury in young female athletes over the athletic season. In particular, the protective effect of the CORE intervention was most evident for reducing knee injuries.

Authors^{23–26} of several meta-analyses have shown that NMT has a positive effect in reducing the incidence of ACL injury in adolescent female athletes. Considerable debate persists about the effect of an NMT intervention on ACL injury reduction in terms of the specific exercises included (eg, strength, balance, plyometrics) as well as duration, frequency, and athlete compliance.^{24,27} The CORE intervention that we implemented in this study in the preseason and continued throughout the competitive season included exercises focused on the trunk and hip. The protocol for this randomized controlled trial was modified from a previously published injury-prevention training program.^{19,20} We modified the exercises to allow ATs and coaches to incorporate the program into team practice so that the exercises would be performed in a timely but effective manner. Anterior hopping, lateral hopping, trunk flexion, trunk extension, trunk rotation, hip extension, lunges, and plyometrics were progressed throughout the protocol to become more advanced as the program continued. Video analysis of ACL injuries suggested that lateral trunk flexion and medial knee collapse were common positions during an ACL injury.^{28,29} Therefore, athletes with decreased control of the trunk may be at higher risk of sustaining an ACL injury, and subsequently, NMT aimed at improving trunk control may improve these mechanics.^{13,19,29–31} As hypothesized, athletes targeted with exercises focused on the trunk and hip in the CORE intervention group had a reduced incidence of all injuries across levels and sports.

An estimated 15.5 million people participate in soccer in the United States. Youth soccer participation is growing at a rate of 11% to 22% per year.^{32,33} Soccer is the leading source of reported sport-related injury in girls.¹⁵ Each year, athletes (mean age = 13 years³³) receive medical attention in US emergency departments for an estimated 1.6 million soccer-related injuries. Powell and Barber-Foss¹⁶ reported an incidence rate of 5.3 injuries per 1000 AEs in soccer. The injury rates of the CORE and SHAM groups for soccer were not different (5.47 and 7.64, respectively; $F_{1,150} = 1.92$, $P = .17$), as the trial was likely underpowered to examine individual sports. Given that soccer was not a school-sponsored sport at the middle school level, our trial had a much smaller sample size for soccer than for the other 2 sports at this level. Therefore, the conclusion that no effect was present for injury incidence between intervention groups should be interpreted with caution.³⁴ With a larger sample size, the positive effects observed in basketball and volleyball might also be seen in soccer at this level, especially as a reduction was evident in older female athletes.³⁴ Replication of this interventional study with a larger sample of soccer athletes, particularly at this younger age level, is a worthy endeavor.^{35,36}

Basketball continues to be a popular team sport in the United States, and it is associated with the most sport-related injuries: 40% more than boys' American football.^{37,38} Researchers^{15,33,39,40} studying high school athletes have indicated that ankle sprain is the most common injury and injury location. Female athletes are also at a

substantially higher risk of ACL injury than male athletes when playing basketball. One in approximately 80 female high school basketball players will sustain an ACL injury.^{23,39,40} For the safety and long-term well-being of our female athletes, we should focus on implementing injury-prevention interventions at a young age. Our data showed a difference in injury rates between the CORE and SHAM groups (4.99 and 7.72 injuries/1000 AEs, respectively; $P = .002$). This difference was also evident at the high school level (3.32 and 7.21 injuries/1000 AEs, respectively; $P = .001$) but not at the middle school level (6.14 and 7.90 injuries/1000 AEs, respectively; $P = .14$).

Similar to basketball, the volleyball data showed a protective effect of the CORE intervention versus the SHAM intervention and a statistically lower injury incidence rate (5.74 and 11.63 injuries/1000 AEs, respectively; $P = .001$). However, the effect of level for volleyball was opposite that for basketball, with an overall greater preventive effect of the CORE intervention observed at the middle school than at the high school level (4.03 and 5.94 injuries/1000 AEs, respectively).

We focused on the specific effects on knee and ankle injuries because researchers have shown that these joints are the 2 most injured body parts in children aged 5 to 14 years presenting to emergency departments⁴¹ or due to athletic participation.^{6,42} For knee injuries, the CORE intervention demonstrated a lower incidence rate for overall injuries; however, a sport-specific difference between intervention groups was demonstrated only in volleyball. Of particular importance was the effect at the middle school level. Based on our data, the greatest effect will likely result from initiating preventive interventions in this younger age group, which is consistent with current evidence.³⁵ Authors^{36,43–45} of longitudinal biomechanical investigations have indicated that a potential window of opportunity may exist before the peak injury incidence, which would be optimal timing for initiating integrative NMT in female athletes. Similarly, young female athletes tend to be particularly sensitive to the effects of integrative NMT, suggesting a potential sex-specific opportunity for enhancing implementation. These previous results support our finding of an enhanced injury-prevention effect in younger athletes.

In research on a similar population, Barber Foss et al¹⁸ reported that the highest incidence of all new cases of patellofemoral pain occurred in middle school-aged adolescent athletes. We found no differences between intervention groups overall, by sport, or by level for ankle injuries. However, given that a small number of ankle injuries were reported, these results should be interpreted with caution.

Our study had limitations, including the small sample size for middle school soccer players. Whereas we tested all sixth- through eighth-grade middle school teams in basketball and volleyball, soccer was not a school-sponsored sport at the middle school level. Only 1 middle school offered a school-based soccer team, but the competitions occurred through a community league. Future research in which additional soccer teams at this age level are examined would be beneficial for determining if the injury-incidence trend evident in our data holds true.

CONCLUSIONS

Participation in the CORE intervention program reduced injury incidence compared with participation in a SHAM intervention. Thus, the CORE intervention program offered protection against injury in young female athletes over the athletic season. Our data indicated that NMT implemented at the middle school and high school levels prevented injury in basketball and volleyball athletes. Of particular interest was the knee-injury reduction observed for middle school volleyball athletes. These data might reflect an important window of opportunity for implementing injury-prevention strategies at younger ages to have the greatest effects on the susceptible female population.

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