

JOURNAL CLUB

Effect of Neuromuscular Warm-up on Injuries in Female Soccer and Basketball Athletes in Urban Public High Schools

Cluster Randomized Controlled Trial

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Objective: To determine the effectiveness of coach-led neuromuscular warm-up on reducing lower extremity (LE) injuries in female athletes in a mixed-ethnicity, predominantly low-income, urban population.

Design: Cluster randomized controlled trial.

Setting: Chicago public high schools.

Participants: Of 258 coaches invited to participate, 95 (36.8%) enrolled (1558 athletes). Ninety coaches and 1492 athletes completed the study.

Interventions: We randomized schools to intervention and control groups. We trained intervention coaches to implement a 20-minute neuromuscular warm-up. Control coaches used their usual warm-up.

Main Outcome Measures: Coach compliance was tracked by self-report and direct observation. Coaches reported weekly athlete exposures (AEs) and LE injuries causing a missed practice or game. Research assistants interviewed injured athletes. Injury rates were compared between the control and intervention groups using χ^2 and Fisher exact tests. Significance was set at $P < .05$. Poisson regression analysis adjusted for clustering and

covariates in an athlete subset reporting personal information ($n=855$; 57.3%).

Results: There were 28 023 intervention AEs and 22 925 control AEs. Intervention coaches used prescribed warm-up in 1425 of 1773 practices (80.4%). Intervention athletes had lower rates per 1000 AEs of gradual-onset LE injuries (0.43 vs 1.22, $P < .01$), acute-onset noncontact LE injuries (0.71 vs 1.61, $P < .01$), noncontact ankle sprains (0.25 vs 0.74, $P = .01$), and LE injuries treated surgically (0 vs 0.17, $P = .04$). Regression analysis showed significant incidence rate ratios for acute-onset noncontact LE injuries (0.33; 95% CI, 0.17-0.61), noncontact ankle sprains (0.38; 95% CI, 0.15-0.98), noncontact knee sprains (0.30; 95% CI, 0.10-0.86), and noncontact anterior cruciate ligament injuries (0.20; 95% CI, 0.04-0.95).

Conclusion: Coach-led neuromuscular warm-up reduces noncontact LE injuries in female high school soccer and basketball athletes from a mixed-ethnicity, predominantly low-income, urban population.

Trial Registration: clinicaltrials.org Identifier: NCT01092286.

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SINCE THE PASSAGE OF TITLE IX in 1972, girls' participation in high school sports has increased more than 900%.¹ Accordingly, girls' sports-related injuries have become an increasing concern. In girls' high school sports, injury

adolescent girls experience higher rates of lower extremity (LE) injuries, especially at the knee and ankle.³⁻¹¹ Knee injuries are the most common cause of permanent disability in female high school basketball



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rates per 1000 athlete exposures (AEs) are highest in soccer (2.36) and basketball (2.01).² In these sports, compared with adolescent boys and prepubescent girls,

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players, accounting for up to 91% of season-ending injuries and 94% of inju-

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ries requiring surgery.^{12,13} In the United States, 20 000 to 80 000 high school female athletes experience anterior cruciate ligament (ACL) injuries each year, with most in soccer and basketball.^{8,14,15}

Long-term studies¹⁶⁻²³ show that despite treatment, knee and ankle injuries increase the risk of premature osteoarthritis. In addition, treatment costs can be substantial. For example, ACL injuries commonly require surgery, extensive rehabilitation, or both, costing between \$17 000 and \$25 000 per injury.^{24,25} Finally, sports-related injuries can limit future participation in physical activity, which has well-known benefits for female adolescents, including enhanced academic success, improved bone health, and lower rates of obesity, diabetes, pregnancy, and depression.²⁶⁻³²

For all these reasons, effective injury prevention is needed, especially in mixed-ethnicity, predominantly low-income, urban populations in which sustained involvement in physical activities is critical to reducing the higher rates of adolescent obesity, diabetes, and pregnancy in these populations.³³⁻³⁵ Coach-led neuromuscular training (NMT), during preseason or as in-season warm-up, has been shown to reduce LE injuries in adolescent female soccer and basketball athletes.³⁶⁻⁴² Neuromuscular training combines progressive strengthening, balance, plyometric, and agility exercises with education on avoiding dynamic knee valgus, a position that increases ACL injury risk, and landing jumps with flexed hips and knees, which reduces ACL strain.⁴³⁻⁴⁶ However, no studies, to our knowledge, have examined either type of coach-led NMT in mixed-ethnicity, predominantly low-income, urban populations, in which practice conditions are often erratic, there are no athletic trainers, and access to medical care is lacking for most athletes.

The study goals were (1) to determine whether urban public high school coaches can consistently implement a neuromuscular warm-up and (2) to measure its effect on noncontact LE injuries in female soccer and basketball athletes. We hypothesized that (1) implementation would be feasible in this mixed-ethnicity, predominantly low-income, urban population and (2) noncontact LE injuries would be reduced in a dose-related manner.

METHODS

The Children's Memorial Hospital (Chicago, Illinois) institutional review board and the Chicago Public Schools research review board approved this study. The Chicago Public Schools research review board permitted collection of AE data without parent consent but required signed parent consent and child assent for the collection of data regarding athlete characteristics and injuries.

COACH AND TEAM RECRUITMENT AND RANDOMIZATION

In 2006, we invited all 258 head girls' soccer and basketball coaches of varsity, junior varsity, sophomore, and freshman teams at Chicago public high schools to participate in this study. There were no specific exclusion criteria. The research coordinator contacted eligible coaches via e-mail, telephone, and

presentations at mandatory coach meetings and then consented and enrolled coaches.

Before randomizing, we stratified schools by school population socioeconomic status and competitive division because we expected that these factors might affect injury rates due to different playing intensity, overall fitness, and access to medical care. To minimize contamination bias, we cluster randomized coaches by school to intervention or control groups. The statistician generated the randomization sequence using an online random number generator program. The research coordinator (J.G.) informed coaches of their allocation. The research assistants (RAs) were not blinded to group assignments. The principal investigator and coinvestigators were blinded until data collection was complete to avoid bias in answering RAs' questions regarding injury classification.

Schools were divided into 4 socioeconomic groups based on percentage of students eligible for subsidized lunch (>90%, 70%-89%, 50%-69%, and <50%).⁴⁷ In the Chicago public high school athletic league, basketball has 3 competitive divisions, and soccer has 4 competitive divisions. All teams play intradivision and interdivision games. Compared with teams in the lower 2 competitive divisions, teams in the higher 2 divisions have higher winning percentages, practice more frequently, hold tryouts for participation, and include mostly athletes who play their sport year-round. Twelve schools had both basketball and soccer teams enrolled; the competitive division was the same for basketball and soccer in 5 of these schools, higher for basketball in 6, and higher for soccer in 1. We stratified these schools based on the basketball team's competitive division.

INTERVENTION

Intervention coaches attended a 2-hour training session led by the principal investigator (C.R.L.) and head athletic trainer (M.R.H.) 2 weeks before their 2006-2007 season. At this session, coaches learned how to implement the full 20-minute neuromuscular warm-up before team practices and an abbreviated version (dynamic motion exercises only) before games (eTable 1; <http://www.archpediatrics.com>). The present warm-up is similar to previously studied NMT programs, combining progressive strengthening, plyometric, balance, and agility exercises. Athletes were instructed to avoid dynamic knee valgus and to land jumps with flexed hips and knees. We taught coaches how to distinguish proper from improper form and how to use verbal cues to promote proper form (eg, "land softly" and "don't let knees cave inward") because research³⁹ shows that this feedback enhances effectiveness. Coaches received a DVD with narrated videos of the exercises, a laminated card listing the order and frequency of exercises for use on the court or field, and printed educational materials about knee injury risk factors and neuromuscular exercises. Training costs were tracked and included personnel time, travel, and coach toolkits (DVD, laminated card, and printed educational materials).

Three RAs attended team practices biweekly to collect exposure and injury data, observe warm-up, and answer questions. We did not provide specific warm-up exercises for control coaches. Instead, we instructed them to perform their usual warm-up. We taught them the prescribed warm-up after the 2006-2007 season.

ATHLETE CHARACTERISTICS

For all athletes on enrolled teams, we sought signed parent consent for inclusion of athlete personal information. Athletes with parent consent completed surveys at the start of their season (or as soon as signed consent was received) to report the following information: date of birth, number of years playing bas-

ketball or soccer, participation in other organized sports, participation in a supervised strength and conditioning program within 3 months of the start of the 2006-2007 season, details of previous sports-related injuries, and race/ethnicity (American Indian/Alaskan native, Asian, black/African American, Hispanic, Native Hawaiian/Pacific Islander, white, and other). Athletes who chose more than 1 category for race/ethnicity were categorized as multiracial. We obtained heights and weights for consented athletes from their 2006-2007 preparticipation physical forms, and then we calculated body mass index.

AEs AND INJURY DATA

All the coaches were given forms to record which athletes participated in each practice and game and all injuries occurring during a practice or game resulting in time loss from a practice or game. Three RAs (students in physical therapy, medicine, and advanced practice nursing) collected the coaches' completed forms weekly.

The RAs interviewed injured athletes to obtain injury date, mechanism (ie, contact with another player vs contact with equipment vs noncontact; acute onset vs gradual onset), injured body part, injury type (eg, sprain, fracture, or contusion), type of medical evaluation, treatment, and games and practices missed due to injury. Interviewing occurred as soon as possible after injury to minimize recall bias. All the interviews were completed by the end of the respective sports season. When available, physician's notes, imaging study reports, and operative notes were obtained to confirm diagnoses. All the ACL injuries were verified by magnetic resonance imaging reports or operative notes. For injured athletes without signed consent at the time of injury, RAs obtained consent before conducting injury interviews and having athletes complete the personal information survey.

We reported injury rates as number of injuries per 1000 AEs, and we defined an AE as 1 athlete participating in all or part of a practice or game. We calculated rates for gradual-onset LE injuries, acute-onset noncontact LE injuries, noncontact ankle sprains, noncontact knee sprains, and noncontact ACL sprains.

FEASIBILITY

We assessed the feasibility of coaches consistently implementing the warm-up by tracking coach compliance. Intervention coaches recorded on their weekly forms whether they used the warm-up before each practice and game that week. The RAs observed most intervention coaches at 1 to 3 practices and most control coaches at least once, documenting the warm-up exercises performed.

STATISTICAL METHODS

For the entire sample, we used the χ^2 and Fisher exact tests to compare injury rates between intervention and control groups and between competitive divisions. Baseline characteristics were compared between groups using *t* tests for continuous variables and χ^2 tests for categorical variables. We calculated the number needed to train to prevent 1 injury as the inverse of the difference between percentages of injured players in the intervention and control groups. We used the Cochran-Armitage test for trend to assess the relationship between frequency of warm-up use and acute-onset LE injury rate. We regarded 2-tailed $P < .05$ as statistically significant.

For the athlete subset that reported personal information, we performed an additional analysis using intent-to-treat Poisson regression models, normalized by AEs, to identify associations between injury rates (gradual-onset LE injuries, acute-onset noncontact LE injuries, noncontact ankle sprains,

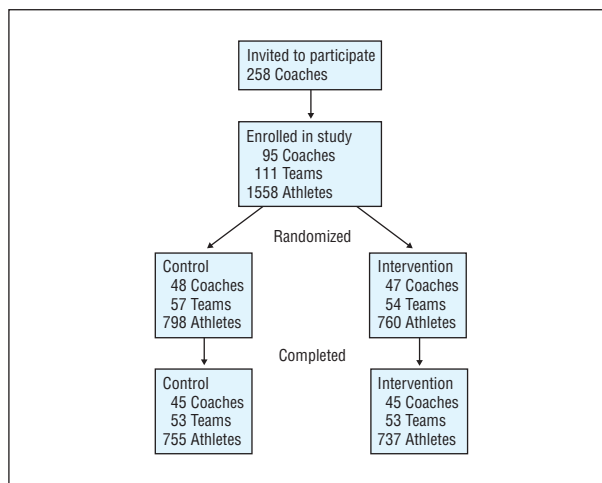


Figure. Flowchart of basketball and soccer coaches, teams, and athletes as participants.

noncontact knee sprains, and noncontact ACL injuries) and the effect of intervention while adjusting for potential confounders (sport, age, race/ethnicity, height, weight, body mass index, years of playing experience, previous knee sprain or ACL injury, strength/conditioning program in previous 3 months, playing on multiple sports teams, and the team's competitive division). The adjustment for covariates is to guard against any bias that may have been introduced as a result of selecting a subset of athletes who reported personal information. We used generalized estimating equations to account for clustering effect by team. Poisson regression produced incidence rate ratio estimates with 95% CIs. The most appropriate models were selected for each injury type based on stepwise selection criteria where each variable had to maintain $P < .10$ for inclusion in the final models. All the analyses were performed using a commercially available statistical software program (SAS/STAT, version 9.2; SAS Institute, Inc, Cary, North Carolina).

RESULTS

SCHOOL, TEAM, AND COACH CHARACTERISTICS

Of 258 coaches invited to participate, 95 (36.8%) enrolled in the study, representing 36 of 80 (45.0%) Chicago public high schools offering girls' basketball or soccer (**Figure**). Some enrolled coaches led multiple teams (ie, varsity and junior varsity), so there were more enrolled teams ($n=111$) than coaches ($n=95$). The main reason coaches gave for declining to participate was lack of time or interest in collecting AE and injury data. Less common reasons included satisfaction with current warm-up and inability to attend the training session.

Of 95 coaches randomized, 90 (94.7%) completed the study. Five coaches submitted no data for their single teams. One coach reported data for only 1 of his 2 teams. These 6 teams were excluded from the analysis. Dropout rates were 6% for control coaches and 4% for intervention coaches.

The geographic distribution (eFigure) and student populations of the 36 participating schools were similar to those of Chicago public high schools overall. At participating schools during the 2006-2007 school year, 81%

Table 1. Characteristics of the 855 Athletes Who Provided Personal Information

| Characteristic | Control Group | | Intervention Group | | P Value |
|--|----------------------------|----------------------|----------------------------|----------------------|---------|
| | Athletes, No. ^a | Mean (SD) or No. (%) | Athletes, No. ^a | Mean (SD) or No. (%) | |
| Age, y | 348 | 16.22 (1.06) | 462 | 16.19 (1.53) | .70 |
| Height, cm | 257 | 162.54 (8.95) | 412 | 163.93 (10.09) | .07 |
| Weight, kg | 257 | 63.02 (13.00) | 411 | 62.30 (11.46) | .47 |
| BMI | 257 | 23.88 (4.61) | 411 | 23.09 (4.09) | .03 |
| Years playing sports | 340 | 4.37 (3.21) | 447 | 4.84 (3.37) | <.05 |
| Participated in strength and conditioning program in past 3 mo | 370 | 155 (41.89) | 485 | 247 (50.93) | .02 |
| Plays on other teams (same sport) | 370 | 88 (23.78) | 485 | 109 (22.47) | .59 |
| Plays on other teams (different sport) | 370 | 141 (38.11) | 485 | 230 (47.42) | .01 |
| Previous knee sprain | 370 | 27 (7.30) | 485 | 33 (6.80) | .78 |
| Previous ACL tear | 370 | 3 (0.80) | 485 | 6 (1.20) | .55 |
| Race/ethnicity | 370 | | 485 | | |
| Black/African American | | 159 (42.90) | | 147 (30.31) | <.001 |
| Hispanic | | 135 (36.49) | | 175 (36.08) | |
| White | | 29 (7.84) | | 48 (9.90) | |
| Other ^b and multiracial ^c | | 28 (7.57) | | 97 (20.00) | |

Abbreviations: ACL, anterior cruciate ligament; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared).

^aNumber of athletes with data available for each variable.

^bOther includes American Indian/Alaskan native, Asian, and Native Hawaiian/Pacific Islander.

^cMultiracial includes participants who selected more than 1 race.

Table 2. Comparison of Noncontact LE Injury Rates^a Between the Control and Intervention Groups in the Entire Sample

| Injury Type | Control Group | | | Intervention Group | | | IRR (95% CI) | P Value |
|---|---------------|----------|-------------|--------------------|----------|-------------|------------------|-------------------|
| | Injuries, No. | AEs, No. | Injury Rate | Injuries, No. | AEs, No. | Injury Rate | | |
| Gradual onset | 28 | 22 925 | 1.22 | 12 | 28 023 | 0.43 | 0.35 (0.18-0.69) | <.01 ^b |
| Acute onset | 37 | 22 925 | 1.61 | 20 | 28 023 | 0.71 | 0.44 (0.26-0.76) | <.01 ^b |
| Ankle sprains | 17 | 22 925 | 0.74 | 7 | 28 023 | 0.25 | 0.34 (0.14-0.81) | .01 ^b |
| Knee sprains | 11 | 22 925 | 0.48 | 6 | 28 023 | 0.21 | 0.45 (0.17-1.21) | .08 ^b |
| ACL sprains | 6 | 22 925 | 0.26 | 2 | 28 023 | 0.07 | 0.27 (0.06-1.35) | .09 ^c |
| LE injuries treated surgically ^d | 4 | 22 925 | 0.17 | 0 | 28 023 | 0 | NA | .04 ^c |

Abbreviations: ACL, anterior cruciate ligament; AE, athlete exposure; IRR, incidence rate ratio; LE, lower extremity; NA, not applicable.

^aInjury rate indicates the number of injuries per 1000 AEs.

^bBy χ^2 test.

^cBy Fisher exact test.

^dAll the surgical procedures were for ACL tears.

of students were from households with an annual income less than \$28 000, and 61% of students graduated within 5 years (vs 83% and 53%, respectively, in Chicago public schools overall).⁴⁸

CHARACTERISTICS OF THE ATHLETE SUBSET THAT PROVIDED PERSONAL INFORMATION

Of the 1492 athletes completing the study, 855 (57.3%) had parent consent to provide personal information. Compared with the entire athlete sample, the subset that provided personal information had significantly more athletes in the top 2 competitive divisions (78.9% vs 77.2%, $P < .001$) and in the intervention group (62.0% vs 55.0%, $P < .001$). Also, in this subset, intervention athletes had lower body mass indexes, had a different race/ethnicity distribution, had more playing experience, and were more likely to play on other sports teams and to have partici-

pated in strength and conditioning programs in the previous 3 months (**Table 1**).

COST OF TRAINING AND FEASIBILITY (COACH COMPLIANCE)

The cost of training a group of 15 to 20 coaches was \$80 per coach. Teams practiced a mean (SD) of 3.3 (1.5) times per week for a mean (SD) of 13.0 (2.5) weeks. Intervention coaches reported using the prescribed warm-up before a mean (SD) of 80% (21%) of practices (range, 0%-100%; median, 87%). Only 6 of 53 intervention coaches (11.3%) reported prescribed warm-up use for less than 50% of practices. The RAs observed a convenience sample of 28 of 45 intervention coaches (62.2%) at 1 to 3 practices each. All 28 of these coaches used some of the prescribed exercises, and 70% used at least 50% of the prescribed exercises. Intervention coaches who were older, over-

Table 3. Noncontact LE Injury Rates^a and IRRs Adjusted for Clustering and Covariates in the 855 Athletes Who Reported Personal Information

| Injury Type | Control Group | | | Intervention Group | | | IRR (95% CI) | P Value |
|---------------|---------------|----------|-------------|--------------------|----------|-------------|------------------|--------------------|
| | Injuries, No. | AEs, No. | Injury Rate | Injuries, No. | AEs, No. | Injury Rate | | |
| Gradual onset | 14 | 12 467 | 1.12 | 11 | 20 345 | 0.54 | 0.48 (0.18-1.26) | .14 ^b |
| Acute onset | 32 | 12 467 | 2.57 | 18 | 20 345 | 0.88 | 0.33 (0.17-0.61) | <.001 ^b |
| Ankle sprains | 11 | 12 467 | 0.88 | 7 | 20 345 | 0.34 | 0.38 (0.15-0.98) | <.05 ^b |
| Knee sprains | 11 | 12 467 | 0.88 | 6 | 20 345 | 0.29 | 0.30 (0.10-0.86) | .03 ^b |
| ACL sprains | 6 | 12 467 | 0.46 | 2 | 20 345 | 0.10 | 0.20 (0.04-0.95) | .04 ^c |

Abbreviations: ACL, anterior cruciate ligament; AE, athlete exposure; IRR, incidence rate ratio; LE, lower extremity.

^aInjury rate indicates the number of injuries per 1000 AEs.

^bBy χ^2 test.

^cBy Fisher exact test.

weight, or appeared less physically fit tended to include fewer prescribed exercises. No control coaches were observed using any prescribed exercises (most omitted a warm-up or had athletes jog or warm up by themselves).

EFFECT OF THE INTERVENTION ON INJURY RATES FOR THE ENTIRE SAMPLE

There were 22 925 AEs (n=755 athletes) in the control group and 28 023 AEs (n=737 athletes) in the intervention group (**Table 2**). The control group had 96 LE injuries (4.19 per 1000 AEs; 95% CI, 3.35-5.02 per 1000 AEs). The intervention group had 50 LE injuries (1.78 per 1000 AEs; 95% CI, 1.29-2.28 per 1000 AEs). Thirteen control and 3 intervention athletes each sustained 2 LE injuries.

Compared with control athletes, intervention athletes had a 65% reduction in gradual-onset injuries, a 56% reduction in acute noncontact injuries, and a 66% reduction in noncontact ankle sprains. All the athletes with noncontact LE injuries resulting in surgery were in the control group. All the LE surgical procedures were for ACL injuries.

DOSE EFFECT OF THE INTERVENTION

Teams using the warm-up more frequently had lower rates of acute-onset LE injuries, but this was not significant ($P=.42$).

NUMBER NEEDED TO TREAT TO PREVENT 1 INJURY

The number needed to treat to prevent 1 injury ranged from 46 for acute, noncontact LE injuries to 191 for noncontact ACL injuries (eTable 2). To prevent 1 noncontact LE injury resulting in surgery, 189 athletes would need to be trained. This equates to training 16 basketball coaches or 11 soccer coaches, given an average of 12 and 18 players per team for basketball and soccer, respectively.

RELATIONSHIP BETWEEN COMPETITIVE DIVISION AND INJURY RATES

Rates of acute-onset LE injuries and noncontact ankle sprains were higher for teams in the lower vs higher 2 competitive divisions (eTable 3).

ADJUSTMENT FOR COVARIATES IN THE ATHLETE SUBSET THAT PROVIDED PERSONAL INFORMATION

For the athlete subset that provided personal information (n=855), after adjustment for clustering by team and significant covariates, incidence rate ratios showed that the intervention group had lower rates of gradual-onset LE injuries, acute-onset noncontact LE injuries, noncontact ankle sprains, noncontact knee sprains, and noncontact ACL injuries (**Table 3**). The incidence rate ratio for gradual-onset LE injuries was not statistically significant in this athlete subset, as it was in the entire sample. Athlete height was the only covariate in the models that was significantly associated with injury. For each centimeter increase in height, the incidence rate ratio for gradual-onset injury was 0.98 (95% CI, 0.970-0.997; $P=.01$).

COMMENT

To our knowledge, this is the first randomized controlled study to demonstrate that (1) high school coaches in a mixed-ethnicity, predominantly low-income, urban population can implement a neuromuscular warm-up and (2) the warm-up reduces noncontact LE injuries, including ACL injuries, in female basketball and soccer athletes in this population. This study provides the first level I evidence⁴⁹ that NMT reduces ACL injuries while also accounting for significant covariates and clustering by team. Although randomized controlled studies^{38,41,42,50} accounting for team clustering have demonstrated that NMT significantly reduces “overall,” “acute-onset,” “knee or ankle,” and “severe” injuries in adolescent basketball, soccer, and handball, they had insufficient power to show a significant reduction in ACL injuries.

The present results are consistent with those from non-randomized studies showing a reduction in ACL injuries in female adolescent basketball and soccer athletes exposed to NMT during a 6-week preseason (0 vs 0.22 per 1000 AEs, $P=.05$)²⁵ or as coach-led warm-up in-season (0.05 vs 0.47 per 1000 AEs, $P=.001$).³⁷ The present results strengthen these findings with improved methods, including a randomized design and an analysis that accounts for team clustering. The rationale for why NMT reduces ACL injuries is supported by data showing that NMT reduces

excessive knee valgus loads, the primary risk factor for ACL injury during athletic maneuvers.^{43-46,51,52}

COACH INVOLVEMENT

We recruited a substantial minority (36.8%) of eligible coaches. Enrollment may have been higher if it had not been coupled with data collection. Overall, coaches' self-reported compliance with the warm-up was good (80% of practices) and similar to that of previous studies³⁸⁻⁴⁰ of coach-implemented NMT (75%-87%). The present high retention rate (95%) and good compliance reflect that participation was voluntary, which selected for coaches who were highly motivated to use the prescribed warm-up and/or who believed that injury prevention would work. The RA visits to practices to collect data may have also increased compliance. Many eligible coaches did not enroll, primarily owing to lack of time or interest in collecting AE and injury data, suggesting that the program may be more broadly and effectively disseminated if data collection is not required.

Most intervention coaches did not use all the prescribed exercises. Thus, these data likely underestimate the protective effect of the prescribed warm-up and suggest that it may be effective when implemented less frequently. There may be essential exercises or a minimum level of exposure required to reduce injury risk.

Older, overweight, and less physically fit coaches tended to include fewer exercises, suggesting that they may have omitted exercises that they could not demonstrate themselves. Compliance may improve if each coach brings an athlete to the training session to learn demonstration of the exercises.

DOSE EFFECT OF THE INTERVENTION

These results suggest a dose-response relationship between training and reduced LE injury rates. Coach training should emphasize that consistent use of the warm-up may increase effectiveness. A larger study is needed to determine essential exercises and minimum exposure for positive effect.

NUMBER NEEDED TO TRAIN AND COST-EFFECTIVENESS OF THE INTERVENTION

To avoid 1 injury resulting in surgery, 189 athletes would need to be exposed to the warm-up, which equates to training 16 basketball coaches or 11 soccer coaches. The cost of training 16 coaches (\$1280) is substantially less than the estimated treatment cost for 1 ACL injury treated surgically (\$17 000-\$25 000). Formal cost-effectiveness analysis is warranted to explore this further.

LIMITATIONS

This study encompassed only 1 season, so it is unknown whether coaches can implement the warm-up consistently over several seasons or require retraining to maintain compliance. Self-reported coach compliance may be overestimated because most coaches were not observed

to use all the prescribed exercises. The RAs observed fewer control than intervention coaches. Further research should include more direct observation of coach compliance over several seasons to determine essential exercises and exposure frequency required for a positive effect. Injury ascertainment may have been incomplete. Chicago public high schools have no athletic trainers to evaluate injuries, and athletes may not seek medical care because many lack a medical home or health insurance. Therefore, medical records were nonexistent for some injuries. This may have underestimated more specific diagnoses (eg, ACL vs knee sprain). Injury data are subject to recall bias for the few athletes interviewed several weeks after injury. The RAs, being unblinded to athletes' group assignment, could impart bias in injury reporting and classification. We minimized this potential bias by objectively defining injury as one causing missed time from a practice or game, and when a physician's diagnosis was unavailable, RAs consulted the principal investigator, who was blinded to group assignments, to classify injury type.

Owing to the difficulty of obtaining parent consent in this study population, personal information was available only for an athlete subset, which may not be representative of the entire sample. We did not account for differences between groups in preexisting knee pain, which could have affected LE injury rates. Analysis of the dose-response relationship was limited to teams using the warm-up at 40% or more of practices because only 2 coaches reported warm-up use at less than 40% of practices. The few injuries in this study did not allow for analysis of the interaction between covariates and the intervention. A larger study could examine these interactions and potentially identify athletes likely to benefit most from NMT, allowing coaches to better target prevention strategies.

In conclusion, to our knowledge, this is the first randomized controlled study to demonstrate that (1) high school coaches in a mixed-ethnicity, predominantly low-income, urban population can implement a neuromuscular warm-up; (2) the warm-up reduces noncontact LE injuries, including ACL injuries, in female basketball and soccer athletes in this population; (3) the effect is likely dose related; and (4) coach training seems cost-effective. These findings suggest that NMT should be routine in girls' high school soccer and basketball.

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Author Contributions: Dr LaBella had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: LaBella, Huxford, and Kaufer Christoffel. **Acquisition of data:** Grissom. **Analysis and interpretation of data:** LaBella, Grissom, Kim, Peng, and Kaufer Christoffel. **Drafting of the manuscript:** LaBella, Huxford, Grissom, Kim, and Kaufer Christoffel. **Critical revision of the manuscript for important intellectual content:** LaBella, Kim, Peng, and Kaufer Christoffel. **Statistical analysis:** Kim and Peng. **Obtained funding:** LaBella and Grissom. **Administrative, technical, and material support:** Huxford and Grissom. **Study supervision:** LaBella, Huxford, Grissom, and Kaufer Christoffel.

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REFERENCES

- Title IX. Women's Sports Federation Web site. 2010. <http://www.womenssportsfoundation.org/home/athletes>. Accessed August 3, 2011.
- Centers for Disease Control and Prevention (CDC). Sports-related injuries among high school athletes—United States, 2005-06 school year. *MMWR Morb Mortal Wkly Rep*. 2006;55(38):1037-1040.
- DeHaven KE, Lintner DM. Athletic injuries: comparison by age, sport, and gender. *Am J Sports Med*. 1986;14(3):218-224.
- Sullivan JA, Gross RH, Grana WA, Garcia-Moral CA. Evaluation of injuries in youth soccer. *Am J Sports Med*. 1980;8(5):325-327.
- Powell JW, Barber-Foss KD. Sex-related injury patterns among selected high school sports. *Am J Sports Med*. 2000;28(3):385-391.
- Yard EE, Schroeder MJ, Fields SK, Collins CL, Comstock RD. The epidemiology of United States high school soccer injuries, 2005-2007. *Am J Sports Med*. 2008;36(10):1930-1937.
- Borowski LA, Yard EE, Fields SK, Comstock RD. The epidemiology of US high school basketball injuries, 2005-2007. *Am J Sports Med*. 2008;36(12):2328-2335.
- Ingram JG, Fields SK, Yard EE, Comstock RD. Epidemiology of knee injuries among boys and girls in US high school athletics. *Am J Sports Med*. 2008;36(6):1116-1122.
- Fernandez WG, Yard EE, Comstock RD. Epidemiology of lower extremity injuries among U.S. high school athletes. *Acad Emerg Med*. 2007;14(7):641-645.
- Emery CA, Meeuwisse WH, Hartmann SE. Evaluation of risk factors for injury in adolescent soccer: implementation and validation of an injury surveillance system. *Am J Sports Med*. 2005;33(12):1882-1891.
- Darrow CJ, Collins CL, Yard EE, Comstock RD. Epidemiology of severe injuries among United States high school athletes: 2005-2007. *Am J Sports Med*. 2009;37(9):1798-1805.
- Zillmer DA, Powell JW, Albright JP. Gender specific injury patterns in high school varsity basketball. *J Womens Health*. 1993;1:69-76.
- Kujala UM, Taimela S, Antti-Poika I, Orava S, Tuominen R, Myllynen P. Acute injuries in soccer, ice hockey, volleyball, basketball, judo, and karate: analysis of national registry data. *BMJ*. 1995;311(7018):1465-1468.
- Chandy TA, Grana WA. Secondary school athletic injury in boys and girls: a three-year comparison. *Phys Sportsmed*. 1985;13(3):106-111.
- von Porat A, Roos EM, Roos H. High prevalence of osteoarthritis 14 years after an anterior cruciate ligament tear in male soccer players: a study of radiographic and patient relevant outcomes. *Ann Rheum Dis*. 2004;63(3):269-273.
- Gillquist J, Messner K. Anterior cruciate ligament reconstruction and the long-term incidence of gonarthrosis. *Sports Med*. 1999;27(3):143-156.
- Ruiz AL, Kelly M, Nutton RW. Arthroscopic ACL reconstruction: a 5-9 year follow-up. *Knee*. 2002;9(3):197-200.
- Myklebust G, Holm I, Maehlum S, Engebretsen L, Bahr R. Clinical, functional, and radiologic outcome in team handball players 6 to 11 years after anterior cruciate ligament injury: a follow-up study. *Am J Sports Med*. 2003;31(6):981-989.
- Gelber AC, Hochberg MC, Mead LA, Wang NY, Wigley FM, Klag MJ. Joint injury in young adults and risk for subsequent knee and hip osteoarthritis. *Ann Intern Med*. 2000;133(5):321-328.
- Lohmander LS, Ostenberg A, Englund M, Roos H. High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior cruciate ligament injury. *Arthritis Rheum*. 2004;50(10):3145-3152.
- Daniel DM, Stone ML, Dobson BE, Fithian DC, Rossman DJ, Kaufman KR. Fate of the ACL-injured patient: a prospective outcome study. *Am J Sports Med*. 1994;22(5):632-644.
- Drawer S, Fuller CW. Propensity for osteoarthritis and lower limb joint pain in retired professional soccer players. *Br J Sports Med*. 2001;35(6):402-408.
- Roos EM. Joint injury causes knee osteoarthritis in young adults. *Curr Opin Rheumatol*. 2005;17(2):195-200.
- de Loës M, Dahlstedt LJ, Thomée R. A 7-year study on risks and costs of knee injuries in male and female youth participants in 12 sports. *Scand J Med Sci Sports*. 2000;10(2):90-97.
- Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes. A prospective study. *Am J Sports Med*. 1999;27(6):699-706.
- Miller KE, Sabo DF, Farrell MP, Barnes GM, Melnick MJ. Sports, sexual behavior, contraceptive use, and pregnancy among female and male high school students: testing cultural resource theory. *Sociol Sport J*. 1999;16(4):366-387.
- King AC, Tribble DL. The role of exercise in weight regulation in nonathletes. *Sports Med*. 1991;11(5):331-349.
- Sallis JF, McKenzie TL, Kolody B, Lewis M, Marshall S, Rosengard P. Effects of health-related physical education on academic achievement: project SPARK. *Res Q Exerc Sport*. 1999;70(2):127-134.
- Baranowski T, Cooper DM, Harrell J, et al; STOPP-T2D Prevention Study Group. Presence of diabetes risk factors in a large U.S. eighth-grade cohort. *Diabetes Care*. 2006;29(2):212-217.
- Jago R, Harrell JS, McMurray RG, Edelstein S, El Ghormli L, Bassin S. Prevalence of abnormal lipid and blood pressure values among an ethnically diverse population of eighth-grade adolescents and screening implications. *Pediatrics*. 2006;117(6):2065-2073.
- Kohrt WM, Bloomfield SA, Little KD, Nelson ME, Yingling VR; American College of Sports Medicine. American College of Sports Medicine Position Stand: physical activity and bone health. *Med Sci Sports Exerc*. 2004;36(11):1985-1996.
- Dishman RK, Hales DP, Pfeiffer KA, et al. Physical self-concept and self-esteem mediate cross-sectional relations of physical activity and sport participation with depression symptoms among adolescent girls. *Health Psychol*. 2006;25(3):396-407.
- Wang Y, Beydoun MA. The obesity epidemic in the United States—gender, age, socioeconomic, racial/ethnic, and geographic characteristics: a systematic review and meta-regression analysis. *Epidemiol Rev*. 2007;29(1):6-28.
- Santelli JS, Melnikas AJ. Teen fertility in transition: recent and historic trends in the United States. *Annu Rev Public Health*. 2010;31:371-383.
- Grigsby-Toussaint DS, Lipton R, Chavez N, Handler A, Johnson TP, Kubo J. Neighborhood socioeconomic change and diabetes risk: findings from the Chicago Childhood Diabetes Registry. *Diabetes Care*. 2010;33(5):1065-1068.
- Heidt RS Jr, Sweeterman LM, Carlonas RL, Traub JA, Tekulve FX. Avoidance of soccer injuries with preseason conditioning. *Am J Sports Med*. 2000;28(5):659-662.
- Mandelbaum BR, Silvers HJ, Watanabe DS, et al. Effectiveness of a neuromuscular and proprioceptive training program in preventing anterior cruciate ligament injuries in female athletes: 2-year follow-up. *Am J Sports Med*. 2005;33(7):1003-1010.
- Soligard T, Myklebust G, Steffen K, et al. Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. *BMJ*. 2008;337:a2469. doi:10.1136/bmj.a2469.
- Hewett TE, Ford KR, Myer GD. Anterior cruciate ligament injuries in female athletes: Part 2, a meta-analysis of neuromuscular interventions aimed at injury prevention. *Am J Sports Med*. 2006;34(3):490-498.
- Kiani A, Hellquist E, Ahlqvist K, Gedeberg R, Michaëlsson K, Byberg L. Prevention of soccer-related knee injuries in teenaged girls. *Arch Intern Med*. 2010;170(1):43-49.

41. Emery CA, Rose MS, McAllister JR, Meeuwisse WH. A prevention strategy to reduce the incidence of injury in high school basketball: a cluster randomized controlled trial. *Clin J Sport Med.* 2007;17(1):17-24.
42. Emery CA, Meeuwisse WH. The effectiveness of a neuromuscular prevention strategy to reduce injuries in youth soccer: a cluster-randomised controlled trial. *Br J Sports Med.* 2010;44(8):555-562.
43. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med.* 2005;33(4):492-501.
44. Hewett TE, Myer GD, Ford KR. Anterior cruciate ligament injuries in female athletes: Part 1, mechanisms and risk factors. *Am J Sports Med.* 2006;34(2):299-311.
45. Koga H, Nakamae A, Shima Y, et al. Mechanisms for noncontact anterior cruciate ligament injuries: knee joint kinematics in 10 injury situations from female team handball and basketball. *Am J Sports Med.* 2010;38(11):2218-2225.
46. Myer GD, Ford KR, Khoury J, Succop P, Hewett TE. Development and validation of a clinic-based prediction tool to identify female athletes at high risk for anterior cruciate ligament injury. *Am J Sports Med.* 2010;38(10):2025-2033.
47. US Department of Agriculture. Fiscal year 2007 income eligibility guidelines. http://isbe.net/nutrition/pdf/IFL_student_eligible.pdf.
48. Chicago Public Schools Office of Research. Evaluation and accountability: cohort dropout and graduation rates report, 1999-2010. <http://research.cps.k12.il.us/cps/accountweb/Reports/allschools.html>. Accessed August 4, 2011.
49. US Preventive Services Task Force. *Guide to Clinical Preventive Services.* 2nd ed. Washington, DC: US Dept of Health and Human Services; 1996.
50. Olsen OE, Myklebust G, Engebretsen L, Holme I, Bahr R. Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. *BMJ.* 2005;330(7489):449.
51. Hewett TE, Stroupe AL, Nance TA, Noyes FR. Plyometric training in female athletes: decreased impact forces and increased hamstring torques. *Am J Sports Med.* 1996;24(6):765-773.
52. Myer GD, Ford KR, Palumbo JP, Hewett TE. Neuromuscular training improves performance and lower-extremity biomechanics in female athletes. *J Strength Cond Res.* 2005;19(1):51-60.

Announcement

Trial Registration Required. In concert with the International Committee of Medical Journal Editors (ICMJE), *Archives of Pediatrics and Adolescent Medicine* will require, as a condition of consideration for publication, registration of all trials in a public trials registry (such as <http://ClinicalTrials.gov>). Trials must be registered at or before the onset of patient enrollment. This policy applies to any clinical trial starting enrollment after July 1, 2005. The trial registration number should be supplied at the time of submission.

For details about this new policy, and for information on how the ICMJE defines a clinical trial, see the editorials by DeAngelis et al in the September 8, 2004 (2004;292:1363-1364) and June 15, 2005 (2005;293:2927-2929) issues of *JAMA*. Also see the Instructions to Authors on our Web site: www.archpediatrics.com.

39. Stahmer AC. The basic structure of community early intervention programs for children with autism: provider descriptions. *J Autism Dev Disord.* 2007;37(7):1344-1354.
40. Chasson GS, Harris GE, Neely WJ. Cost comparison of early intensive behavioral intervention and special education for children with autism. *J Child Fam Stud.* 2007;16:401-413.
41. Callahan K, Henson RK, Cowan AK. Social validation of evidence-based practices in autism by parents, teachers, and administrators. *J Autism Dev Disord.* 2008;38(4):678-692.
42. Magiati I, Charman T, Howlin P. A two-year prospective follow-up study of community-based early intensive behavioural intervention and specialist nursery provision for children with autism spectrum disorders. *J Child Psychol Psychiatry.* 2007;48(8):803-812.
43. Dingfelder H, Mandell D. Bridging the research-to-practice gap in autism intervention: an application of diffusion of innovation theory. *J Autism Dev Disord.* 2011;41(5):597-609.
44. Sturm R. Economic grand rounds: the myth of medical cost offset. *Psychiatr Serv.* 2001;52(6):738-740.
45. Baca-Garcia E, Perez-Rodriguez MM, Basurte-Villamor I, et al. Patterns of mental health service utilization in a general hospital and outpatient mental health facilities: analysis of 365 262 psychiatric consultations. *Eur Arch Psychiatry Clin Neurosci.* 2008;258(2):117-123.
46. Fombonne E, Heavey L, Smeeth L, et al. Validation of the diagnosis of autism in general practitioner records. *BMC Public Health.* 2004;4:5. doi:10.1186/1471-2458-4-5.
47. Dodds L, Spencer A, Shea S, et al. Validity of autism diagnoses using administrative health data. *Chronic Dis Can.* 2009;29(3):102-107.
48. Burns T. Hospitalisation as an outcome measure in schizophrenia. *Br J Psychiatry Suppl.* 2007;50:s37-s41.
49. Rupp K, Davies PS, Newcomb C, et al. A profile of children with disabilities receiving SSI: highlights from the National Survey of SSI Children and Families. *Soc Secur Bull.* 2005-2006;66(2):21-48.
50. Young A, Ruble L, McGrew J. Public vs private insurance: cost, use, accessibility, and outcomes of services for children with autism spectrum disorders. *Res Autism Spectr Disord.* 2009;3(4):1023-1033.
51. Semansky RM, Koyanagi C. The TEFRA Medicaid eligibility option for children with severe disabilities: a national study. *J Behav Health Serv Res.* 2004;31(3):334-342.
52. Shattuck PT, Grosse S, Parish S, Bier D. Utilization of a Medicaid-funded intervention for children with autism. *Psychiatr Serv.* 2009;60(4):549-552.
53. Buchanan RJ, Chakravorty BJ. Medicaid home and community-based care waiver programs: providing services to people with AIDS. *Health Care Financ Rev.* 1997;18(4):83-103.
54. Johnson P. Medicaid: Medicaid: waivers—2005: end of year issue brief. *Issue Brief Health Policy Track Serv.* December 31, 2005:1-21.

Correction

Incorrect Data in Table 3 and in Text. In the article titled “Effect of Neuromuscular Warm-up on Injuries in Female Soccer and Basketball Athletes in Urban Public High Schools: Cluster Randomized Controlled Trial” by LaBella et al, published in the November issue of the *Archives* (2011;165[11]:1033-1040), on page 1037, in Table 3, the values in the first 6 columns (“Control” and “Intervention” classifications for “Injuries, No.”; “AEs, No.”; “Injury Rate” subclassifications) are incorrect. Reading from left to right, top to bottom, the value sets for “Gradual onset” should have been 14, 12 467 (for all entries in this column), 1.12 and 11, 20 345 (for all entries in this column), and 0.54. For “Acute onset,” the value sets for “Injuries, No.” and “Injury Rate” should have been 32 and 2.57 and 18 and 0.88; for “Ankle sprains,” 11 and 0.88 and 7 and 0.34; for “Knee sprains,” 11 and 0.88 and 6 and 0.29; and “ACL sprains,” 6 and 0.48 and 2 and 0.10. On the same page, left-hand column, “Effect of the Intervention of Injury Rates for the Entire Sample” subsection of the “Results” section, paragraph 2, the first sentence should have read as follows: “Compared with control athletes, intervention athletes had a 65% reduction in gradual-onset injuries, a 56% reduction in acute, noncontact injuries, and a 66% reduction in noncontact ankle sprains.”