

Sport-Specific Training Targeting the Proximal Segments and Throwing Velocity in Collegiate Throwing Athletes

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Context: The ability to generate, absorb, and transmit forces through the proximal segments of the pelvis, spine, and trunk has been proposed to influence sport performance, yet traditional training techniques targeting the proximal segments have had limited success improving sport-specific performance.

Objective: To investigate the effects of a traditional endurance-training program and a sport-specific power-training program targeting the muscles that support the proximal segments and throwing velocity.

Design: Randomized controlled clinical trial.

Setting: University research laboratory and gymnasium.

Patients or Other Participants: A total of 46 (age = 20 ± 1.3 years, height = 175.7 ± 8.7 cm) healthy National Collegiate Athletic Association Division III female softball ($n = 17$) and male baseball ($n = 29$) players.

Intervention(s): Blocked stratification for sex and position was used to randomly assign participants to 1 of 2 training groups for 7 weeks: a traditional endurance-training group (ET group; $n = 21$) or a power-stability-training group (PS group; $n = 25$).

Mean Outcome Measure(s): The change score in peak throwing velocity (km/h) normalized for body weight (BW; kilograms) and change score in tests that challenge the muscles of the proximal segments normalized for BW (kilograms). We used 2-tailed independent-samples t tests to compare differences between the change scores.

Results: The peak throwing velocity (ET group = 0.01 ± 0.1 km/h/kg of BW, PS group = 0.08 ± 0.03 km/h/kg of BW; $P < .001$) and muscle power outputs for the chop (ET group = 0.22 ± 0.91 W/kg of BW, PS group = 1.3 ± 0.91 W/kg of BW; $P < .001$) and lift (ET group = 0.59 ± 0.67 W/kg of BW, PS group = 1.4 ± 0.87 W/kg of BW; $P < .001$) tests were higher at postintervention in the PT than in the ET group.

Conclusions: An improvement in throwing velocity occurred simultaneously with measures of muscular endurance and power after a sport-specific training regimen targeting the proximal segments.

Key Words: spine, trunk, pelvis-stability exercise training, performance assessment

Key Points

- Simultaneous improvements occurred in throwing velocity and power assessments of the chop and lift maneuvers.
- Training techniques for the proximal segments should aim to provide sport-specific stimuli.
- Assessment of the proximal segments should consider measuring the muscular-endurance, -strength, and -power characteristics of sport.

The synergistic muscle activity of the spine, pelvis, and trunk has been proposed to improve sport performance.¹ In anticipation of movement, the neurologic feed-forward mechanism activates the muscles that stabilize the intervertebral segments of the lumbar spine.² Regardless of the task, the rigid muscular support of the lumbar column provides a proximal base for the muscles of the pelvis and trunk to generate, absorb, and transfer forces throughout the kinetic chain.^{1,3,4} Proximal synergy among the spine, pelvis, and trunk enables ground reaction forces to be converted into high-velocity movements at the extremities, such as those seen in throwing.⁵ Therefore, several authors^{1,3,6–8} have proposed that sport-performance training and assessment techniques should attempt to target the endurance, strength, or power muscle

characteristics of the proximal segments specific to sport. However, current training interventions and assessment practices have been unable to account for the sport-specific contributions of the proximal muscles and their effects on improvements in sport performance.

Improvements in muscular endurance, strength, and electromyographic (EMG) activation relative to the muscles that support the spine, pelvis, and trunk are well documented after training interventions.^{4,9–11} However, these claims have often been supported by studies in which researchers did not use comprehensive techniques that account for improvements to the muscular-endurance, strength, and power characteristics specific to the proximal stabilizers and the sport.^{4,9,12} In many studies,^{8,13–15} authors have not provided data to support the finding that

Table 1. Participant Demographics (Mean \pm SD)

| Intervention Group | n | Sex, female/male | Age, y | Height, cm ^a | Mass, kg | | Hand Dominance, Left/Right | Primary Position | |
|----------------------|----|------------------|----------------|-------------------------|------------------------------|-------------------------------|----------------------------|-----------------------------------|--------------------------------------|
| | | | | | Preintervention ^a | Postintervention ^a | | Pitcher, Female/Male ^b | Nonpitcher, Female/Male ^c |
| Traditional training | 21 | 8/13 | 20.3 \pm 1.3 | 176.3 \pm 8.6 | 80.1 \pm 15.1 | 80.5 \pm 15.7 | 2/19 | 1/4 | 7/9 |
| Power stability | 25 | 9/16 | 19.8 \pm 1.2 | 175.2 \pm 9.0 | 74.1 \pm 12.6 | 74.5 \pm 13.2 | 2/23 | 1/4 | 8/12 |
| Total | 46 | 17/29 | 20.0 \pm 1.3 | 175.8 \pm 8.8 | 77.1 \pm 13.9 | 77.5 \pm 14.5 | 4/42 | 2/8 | 15/21 |

^a Indicates no difference for height and mass between groups ($P \leq .05$).

^b Indicates participants who reported that their primary position was pitcher.

^c Indicates participants who reported a primary position other than pitcher.

improvements in sport are related to improvements in the proximal segments. Myer et al¹² reported improvements in pelvic and trunk stability after a training program specific to the hip and trunk. They concluded that the stability changes could translate into improved performance for sport and injury reduction; however, no sport-performance measures were provided to accompany the stability improvements.¹² Instead, authors have reported that training interventions improved sport performance measures without adequately monitoring change at the proximal segments.^{8,13–15} Saeterbakken et al⁸ reported a 4.9% increase in throwing velocity after a 6-week sling-suspension training program involving unstable surfaces and closed kinetic chain movements. Seiler et al¹⁴ used a similar intervention and reported improvements in golf club velocity among junior golfers, whereas Sato and Mokha¹³ reported improvements in a 5000-m run after an unstable stability-ball strength-training program in middle-aged recreational runners. However, discerning a cause-and-effect relationship is difficult because they did not account for simultaneous improvements in sport performance and the musculature that supports the proximal segments.

Researchers reporting improvements in the proximal-segment musculature have often noted no effect for sport performance, likely because of the commonly used uniplanar and isometric stability interventions and assessment techniques, such as plank maneuvers.^{16–18} Isometric muscular endurance seems to be warranted, regardless of the sport, because of its role in providing stability at the spine in anticipation of movement.^{2,19,20} However, investigators have hypothesized that strength and power movements are generated and transferred via the muscles that support the pelvis and trunk.¹ The literature supports this claim, as muscular-endurance training of the proximal stabilizers has been reported to improve muscular endurance and not explosive muscular power.^{6,9} Thus, several authors have reported improvements in isometric endurance tests ($P < .05$) but not explosive field tests or sport performance after isometric-training interventions.^{16–18,21,22} To date, Stray-Pedersen et al²³ are the only authors to report improvements at the proximal segments as measured by an isometric hip-abduction test ($P < .01$) and ball velocity for a nonapproach soccer kick ($P = .04$) after a limb-suspension intervention training program.²³ However, the isometric hip-abduction assessment test used to evaluate the proximal segments has not been validated in the literature, and this test did not evaluate muscle power specific to the act of kicking.²³

It seems reasonable to consider training and testing the proximal segments with stimuli that account for the muscular demands (endurance, strength, power) specific to sport rather than incorporating stimuli that target only the endurance capacity of the muscle. Monitoring the muscular-endurance, -strength, or -power demands of the proximal segments may be more appropriate for interpreting how training the proximal segments can influence sport. Sports that require more power movements, such as throwing or hitting, would require more strength and power training than endurance events, such as distance running. Therefore, the purpose of our study was to examine the effect of power training and endurance training on the muscles that support the proximal segments and on throwing velocity among National Collegiate Athletic Association Division III softball and baseball players. We hypothesized that a 7-week, sport-specific training intervention targeting muscular power would improve the sport-specific muscle contributions of the proximal segments and result in a faster throwing velocity compared with a traditional muscular-endurance training protocol.

METHODS

Participants

Forty-six healthy, Division III female softball ($n = 17$) and male baseball ($n = 29$) players from the same university volunteered to participate in a training intervention study with preintervention and postintervention measures (Table 1). All participants reported to an information meeting. Players were assigned randomly to 1 of 2 training groups: a traditional endurance-training group (ET group) ($n = 21$; 13 men, 8 women) or a power-stability-training group (PS group) ($n = 25$; 16 men, 9 women) as outlined in Figure 1. The ET group included 1 female and 4 male pitchers and 7 female and 9 male fielders. The PS group included 1 female and 4 male pitchers and 8 female and 12 male fielders. Participants were stratified by an independent investigator who was not part of the assessment team and was not involved in the training sessions. Both groups consisted of returning players with an average experience of 12 ± 3 years in their respective sports. The Tegner Activity Level Scale is a valid and reliable self-reported measure of current activity level; it revealed no difference in activity between the groups (ET group = 7.4 ± 0.15 , PS group = 7.2 ± 0.15 ; $P = .47$).⁷ Inclusion criteria consisted of collegiate, overhead-throwing athletes participating in softball or baseball. Persons reporting any major orthopaedic injury

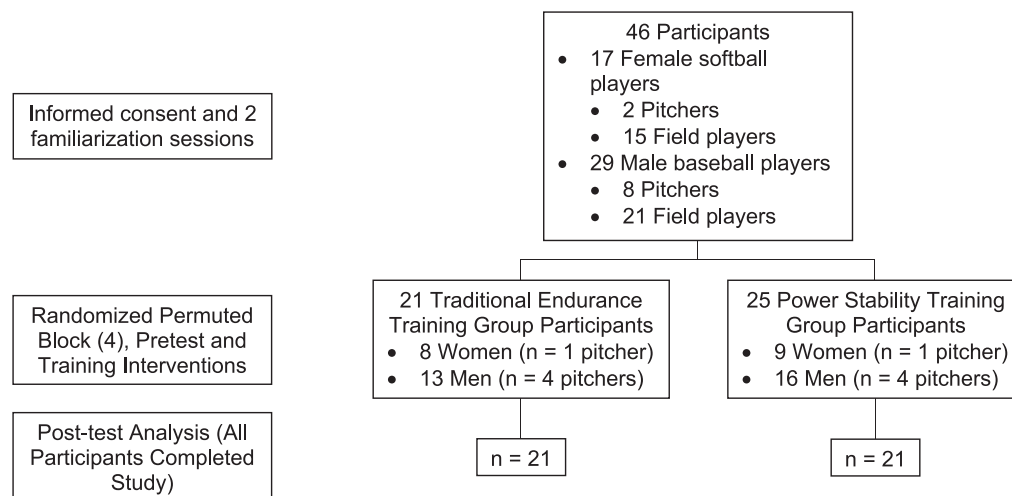


Figure 1. Participant allocations.

within the 3 months before the study that resulted in the inability to perform sport-training activities were excluded from data collection. Attendance was taken at each training session to monitor compliance. All participants provided a written informed consent document, and the study was approved by the Institutional Review Board of the University of Kentucky.

Testing Procedures

Athletes participated in 2 familiarization sessions for all dependent variables, baseline testing, a 7-week intervention, and postintervention testing. Testing and the intervention occurred during the fall off-season training by the same investigative team (T.P. and 2 professional volunteers). The 2 familiarization periods were performed 1 week apart before baseline testing to prevent any potential learning effect for the dependent measures.²⁴ Multiple repetitions were performed to ensure proper technique and adherence to the test protocol.²⁴ The chop and lift 1-repetition maximum (1RM) power protocol testing was performed in a controlled laboratory on the PrimusRS system (BTE Technologies, Hanover, MD).⁷ Throwing velocity assessments²⁵ and isometric endurance planks in the prone²⁶ and dominant upper extremity side⁷ positions were performed in an open gymnasium. *Upper extremity dominance* was designated as the hand most commonly used to write. The orders of power tests and isometric endurance planks (prone, side) were counterbalanced using a Latin-square design. All participants were instructed to produce a maximal effort for each test. We used a 7-week training intervention because researchers have reported training effects for this period.^{9,22} The examiners were blinded to group allocation and had an average of 10 years of experience as certified strength and conditioning professionals and an average of 14 years of experience as certified athletic trainers.

Throwing Velocity Testing. A calibrated handheld professional radar gun (Prospeed; Decatur Electronics, Phoenix, AZ) was used to capture the peak throwing velocity in miles per hour. Before testing, each athlete completed a 5-minute jog, general flexibility exercises, and progressive throwing warm-up. From a flat surface,

participants performed five 2-step throws into a 4-ft² (1.22-m²) target positioned 2 ft (0.61 m) from the ground from a 30-ft (9.15-m) distance with maximal effort. Players were instructed to simulate throwing with maximal force while maintaining control of the ball. A minimum rest of 1 minute was allowed between throws. All attempts that hit the target were recorded and used to calculate the peak and mean throwing velocities and throwing velocities normalized by body weight (BW).²⁵ All participants were able to hit the target with no more than 7 attempts needed.

Chop and Lift Tests. The chop and lift 1RM power protocols were used as previously reported.⁷ Participants viewed a video demonstration of the chop and lift tests while practicing the maneuvers. With participants in a half-kneeling position with the hip and knee flexed to 90°, we placed a 2-in × 6-in × 60-in (5.08-cm × 15.24-cm × 152.4-cm) wood plank flush against and between the knee and foot of the opposite limb. To ensure the comfort of participants, we supported the weight-bearing knee with a standard 46-cm³ × 43-cm³ × 13-cm³ block of medium-density foam pad (Airex AG, Sins, Switzerland). During the chop test, participants held a dowel rod diagonally in the 2 o'clock position, using the bottom hand to grasp the rod with the shoulder slightly flexed, horizontally adducted, and internally rotated and the elbow flexed to 60° to 80° (Figure 2). The top hand grasped the dowel rod with the shoulder slightly flexed, internally rotated, and abducted to approximately 145° to 160°. Participants used their upper extremities to pull (bottom hand) and push (top hand) in a “chopping” diagonal pattern across the torso toward the opposite hip/kneeling limb. The end of the movement was marked by the top hand being in line with the opposite (kneeling) hip and the bottom hand extended behind that same hip. For the lift test, participants held the dowel rod diagonally in the 4:30 position, using the top hand to support the rod across the chest with the shoulder abducted to approximately 130°, the elbow in terminal flexion, and the forearm pronated (Figure 3). The bottom hand/upper extremity was abducted with slight forearm pronation. Participants were instructed to lift the top hand and invert the shoulder and elbow to adducted and flexed positions, respectively. The bottom hand was moved into an overhead

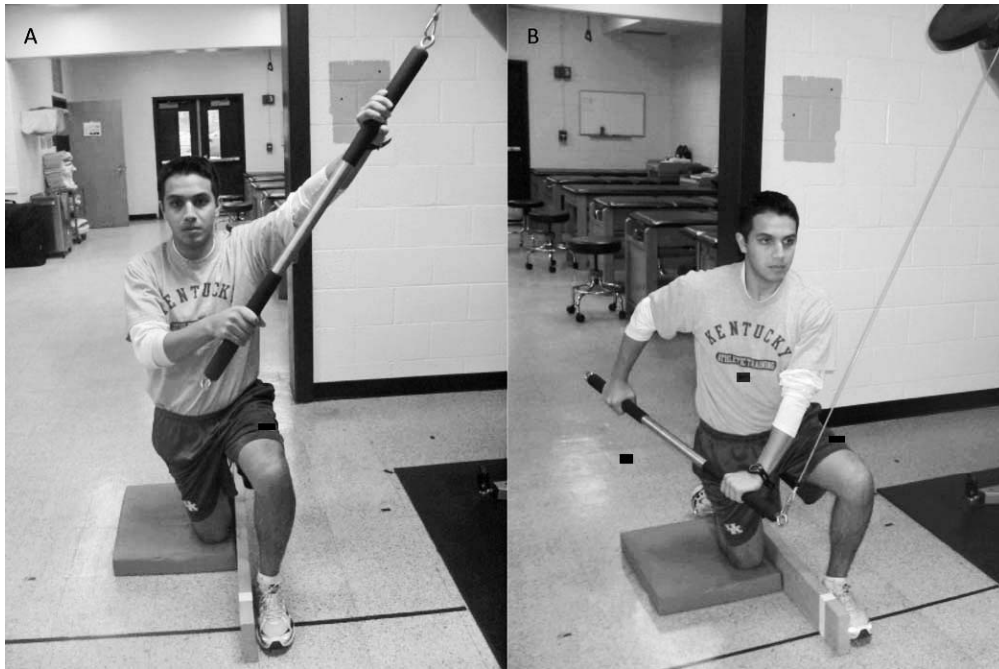


Figure 2. Chop test. A, Beginning position. B, Ending position. Reprinted with permission. Palmer TG, Uhl TL. Interday reliability of peak muscular power outputs on an isotonic dynamometer and assessment of active trunk control using the chop and lift tests. *J Athl Train.* 2011;46(2):150–159.

position with the shoulder internally rotated, horizontally adducted, and flexed.

Chop and Lift Testing Protocol. While looking at a fixed point, participants performed approximately 5 to 10 practice repetitions using a submaximal weight for the chop and lift tests. Initial testing resistance was standardized to 25% and 15% of body mass for the chop and lift tests, respectively.⁷ The dowel-rod weight (1.9 lb [0.86 kg]) was

calculated as part of the test resistance that the PrimusRS system provided. After a successful 1RM, we increased resistance by 5 lb (2.25 kg) for the chop and 3 lb (1.35 kg) for the lift. If participants could not produce a peak power output value that was equal to or greater than that of the previous test trial, resistance was reduced by 3 lb (1.35 kg) for the chop and 1 lb (0.45 kg) for the lift. Resistance was further adjusted in 1-lb (0.45-kg) increments (up or down)

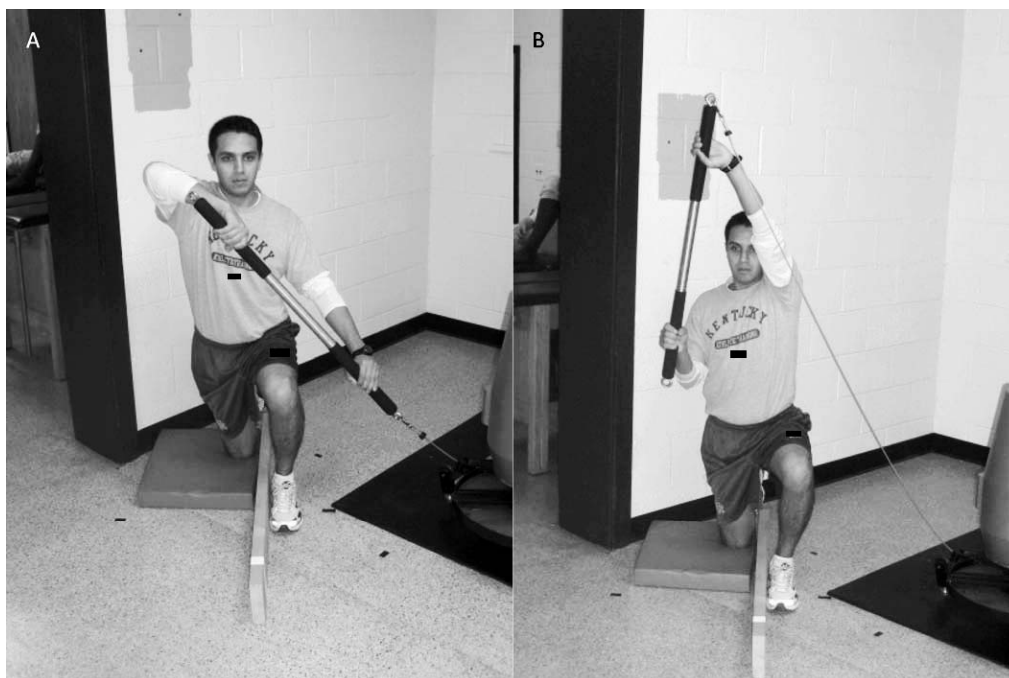


Figure 3. Lift test. A, Beginning position. B, Ending position. Reprinted with permission. Palmer TG, Uhl TL. Interday reliability of peak muscular power outputs on an isotonic dynamometer and assessment of active trunk control using the chop and lift tests. *J Athl Train.* 2011;46(2):150–159.



Figure 4. Prone endurance plank.

until the maximal peak muscular power was achieved. For each test, participants performed a series of 1RM efforts, resting for a minimum of 30 seconds between attempts. Peak muscular power in watts and the number of repetitions (3 ± 1 repetitions) needed to achieve maximal efforts were recorded for the dominant-side throwing arm of both groups at pretest and posttest sessions.⁷

Endurance Planks. Participants were instructed to perform a prone plank with the lower extremities, torso, and body fully extended and suspended bilaterally from the elbows, which were flexed in a 90° position, and the ankle and foot, which were in a neutral position (Figure 4). The side-lying plank was performed with the lower extremities and torso fully extended; the feet stacked; and the dominant shoulder and elbow abducted and flexed to 85° to 90°, respectively. The nonsupport upper extremity was placed across the chest with the hand on the opposite shoulder (Figure 5). Participants were timed in seconds to determine how long they could maintain the neutral position. The test was terminated if the neutral position was disrupted due to fatigue, pain, or fault in trunk position. Deviations of 5° from neutral prompted the examiner to instruct the participant to return to neutral position. If the participant could not comply, the test was terminated and time was recorded.²⁶ Researchers²⁷ have reported that a typical performance ranged from approximately 90 to 240 seconds or more in healthy athletic populations. Therefore, we established a maximal time limit of 4 minutes for the test to be stopped and the time recorded. A 1:4 test-to-rest ratio was used.²⁸ We orally coached and encouraged participants to maintain their static positions throughout the testing protocol but did not disclose the duration of their respective tests at any time during the study.

Training Intervention Programs

Both the ET and PS groups were trained by the same investigators for 30 minutes, 2 times per week, for 7 weeks, for a total of 14 sessions.¹⁶ The training interventions were periodized, consisting of approximately 10 to 15 exercises per exercise session,⁸ and were designed to target the proximal segments. All training sessions consisted of a 5-minute, low-intensity, steady-state jog followed by a general static-flexibility program for the lower extremity, upper extremity, and trunk muscles.¹¹ Volume and intensity for each training session were controlled to have similar training session times for each group. Workload was calculated by multiplying the number of exercises, sets, repetitions, and resistance recorded for each group and each training session throughout the intervention. Program compliance was monitored using attendance sheets.



Figure 5. Side muscular-endurance plank.

Endurance-Training Program. The ET group training was designed to mimic a commonly cited traditional linear and isometric endurance program noted to improve spinal stabilization and purported to improve sport performance.^{9,16,17,21,22} Figure 6 illustrates examples of the muscular-endurance training exercises primarily used for the ET group: static planks (prone, supine, side), torso extension/Superman, flexion/curl-ups, dead bug, bird dog, and lateral muscular-endurance movements.²⁶ Training progressions consisted of increases in static hold times and the number of repetitions or sets for the exercises performed.

Power-Stability-Training Program. The PS training program was a novel training approach, as it incorporated spinal stabilization but emphasized multiplanar, rotational strength, and power resistance techniques that targeted the proximal segments and were sport specific to throwing. The primary training stimuli included muscular strength and power movements progressing from the floor to standing positions and functional movements that were sport specific to the rotational demands of throwing (Figure 7). Resistances were modified to accomplish slow and fast movements for the implementation of strength and power stimuli. Strength movements were slow and controlled for approximately 3 to 8 repetitions, whereas power movements were performed rapidly for 1 to 4 repetitions.¹¹ Perturbation and unstable (narrow split-stance, BOSU stability ball [BOSU, Ashland, OH]) surfaces stimuli were combined with heavy-resistance free weights and medicine balls (Figure 8).¹¹ Heavy resistances were spotted carefully and undulated between strength and power movements.

Statistical Analysis

A randomized controlled clinical trial was implemented with a stratified permuted block method and a preintervention-to-postintervention design. Sex and player position were stratified using blocks of size 4. The independent variables were the ET and PS groups. The main dependent variables of interest were the change in peak throwing velocity in kilometers per hour per kilogram of BW, power-chop test in watts per kilogram of BW, power-lift test in watts per kilogram of BW, prone-plank hold time in seconds, and side-plank hold time in seconds compared between preintervention and postintervention time points.

Normality of the distribution was assessed using the Shapiro-Wilk test and visual observation of the residual plots for the preintervention-to-postintervention measures. We used a 2-tailed independent-samples *t* test to analyze

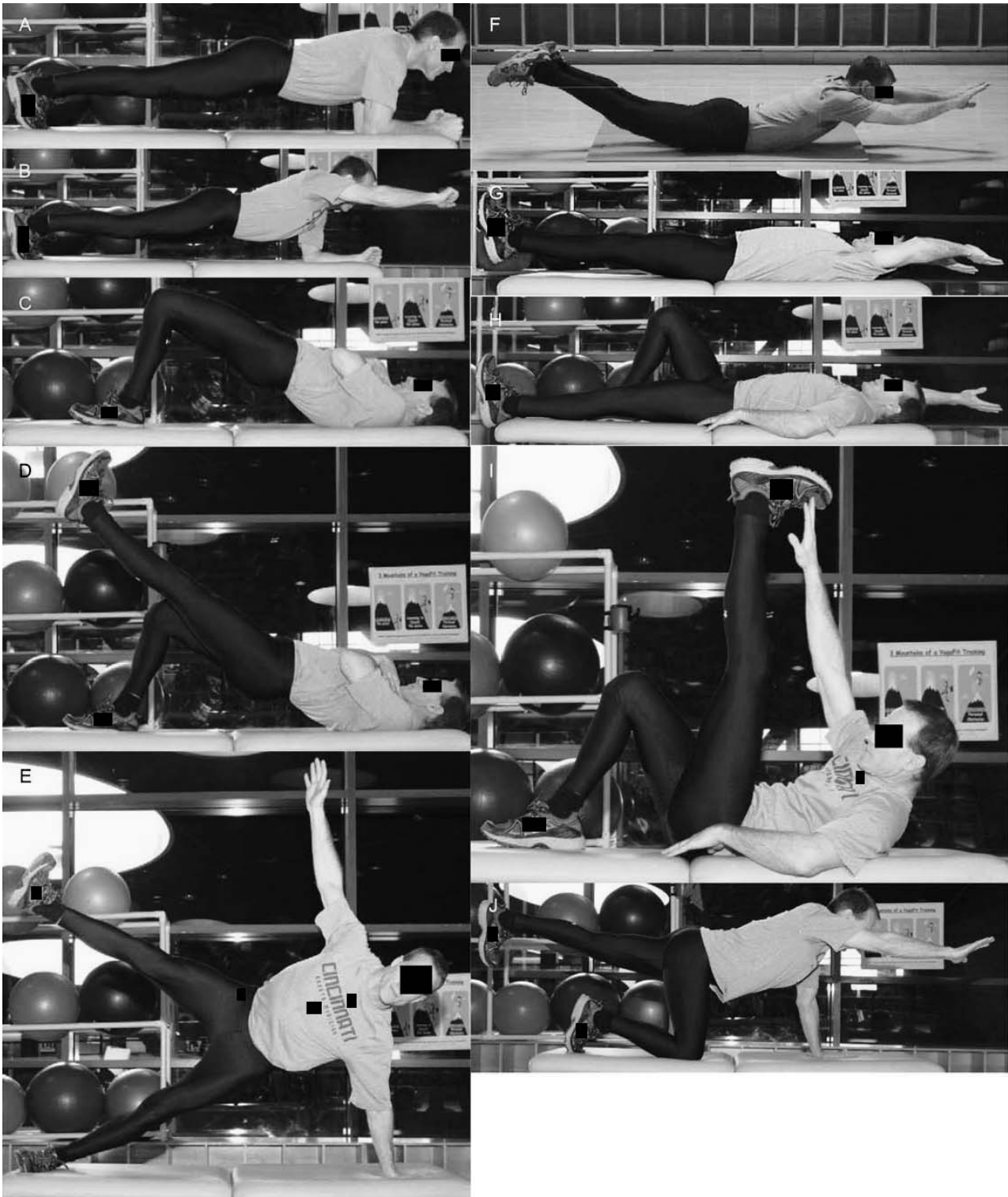


Figure 6. Endurance-training group exercises. A, Prone plank. B, Advanced prone plank. C, Supine plank. D, Advanced supine plank. E, Advanced side plank. F, Torso extension. G, Torso extension-flexion. H, Dead bug beginning position. I, Dead bug ending position. J, Bird dog 4-point ipsilateral/unilateral extensions.

(1) between-groups differences at baseline for height, mass, years of playing experience, and throwing velocity and (2) group differences in change scores for each dependent variable of interest. A dependent paired-samples *t* test was used to analyze throwing velocities from the preintervention to postintervention periods. Percentage change from preintervention to postintervention for throwing velocity

was calculated by dividing preintervention values into the change scores from the posttest. Non-normal distributions for the lift, side-plank, and prone-plank tests were assessed using a Mann-Whitney *U* test. A Pearson product moment correlation was used to assess the relationships among throwing velocity, chop and lift power outputs, and the prone and side-plank hold times. All statistical analyses

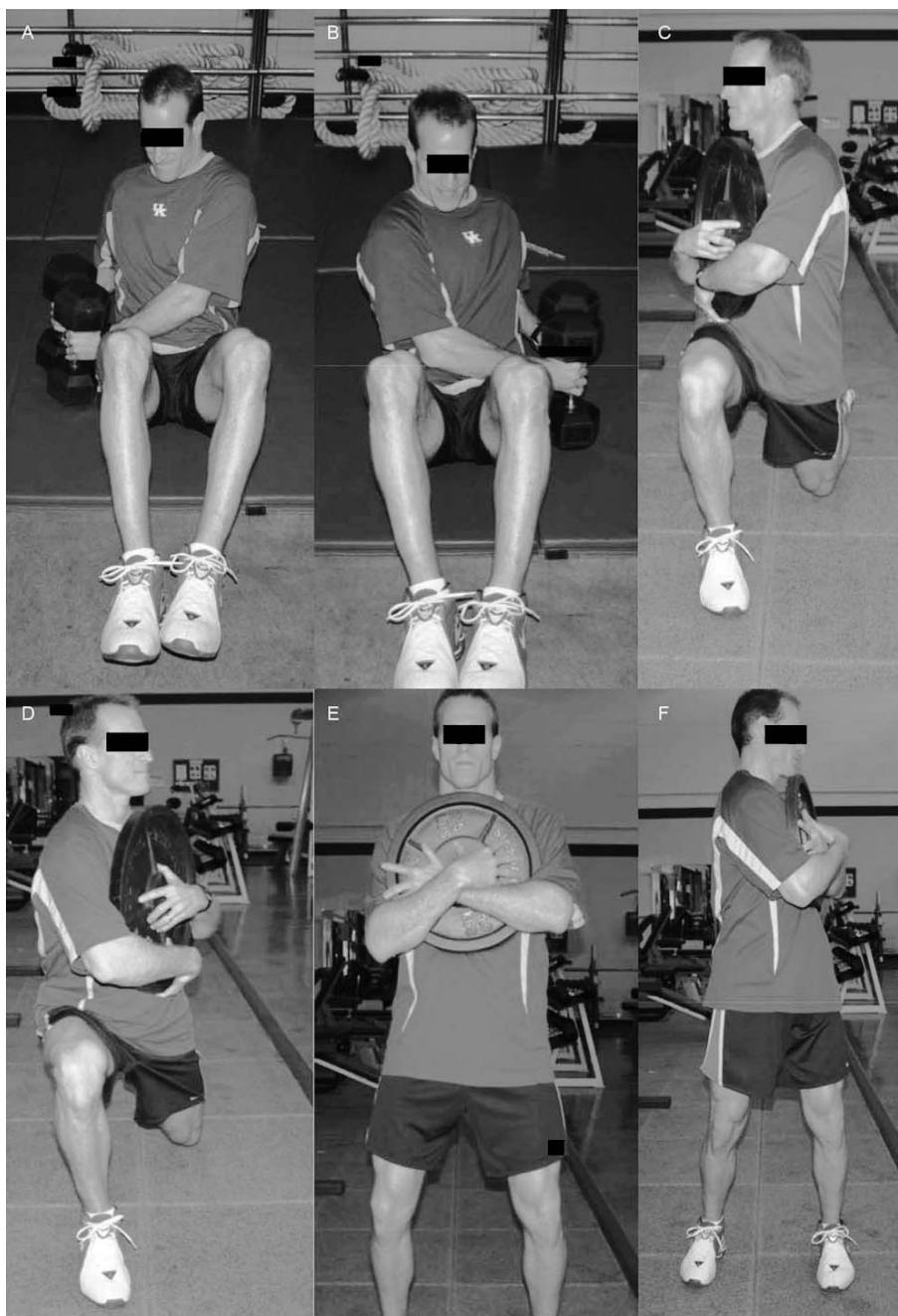


Figure 7. Example of floor-to-standing strength and power resistance exercises. **A,** Seated-to-standing rotation beginning position. **B,** Seated weighted rotations ending position. **C,** In-line lunge weighted-rotation starting position. **D,** In-line lunge weighted-rotation ending position. **E,** Standing weighted-rotation beginning position. **F,** Standing weighted rotation ending position.

were performed using SPSS/PAW software (version 19.0; IBM SPSS, IBM Corporation, Armonk, NY) with the α level set a priori at .05.

RESULTS

We observed no between-groups differences at baseline for height, mass, years of playing experience, and throwing velocity (t_{44} range = 0.4–1.5; $P > .05$). A simultaneous improvement was observed for the change score in peak throwing velocity, the chop test, and the lift test in the PS group but not in the ET group. The change score for throwing velocity was 6% faster in the PS group (0.08 ± 0.03 km/h/kg of BW) than in the ET group (0.01 ± 0.1 km/

h/kg of BW) at postintervention ($t_{44} = 11.6$, $P < .001$), which supports the hypothesis that a power training program would have a positive effect on power assessments of the muscles that support the proximal segments and throwing velocity (Table 2). A dependent paired-samples t test revealed that peak and mean throwing velocities/km/h/kg of BW in the PS group were different from preintervention to postintervention (ET group: $t_{20} = 14.9$, $P = .001$; PS group: $t_{24} = 14.9$, $P = .001$). The ET group had differences for mean throwing velocity/km/h/kg of BW from pretest to posttest ($t_{20} = 5.0$, $P = .02$) but not for normalized peak throwing velocity ($t_{20} = 0.68$, $P = .50$). We observed differences between groups for chop ($t_{44} = 4.1$, $P = .003$) and



Figure 8. Examples of perturbation and unstable-surfaces strength and power training. A, Split-stance in-line lunge perturbation starting position. B, Split-stance in-line lunge perturbation ending position. C, Stability-ball rotations beginning position. D, Stability-ball rotations ending position. E, BOSU (BOSU, Ashland, OH) lateral-flexion starting position. F, BOSU lateral-flexion ending position.

lift ($t_{44} = 3.7$, $P = .004$) power outputs in watts per kilogram of BW. The Mann-Whitney U test indicated no change score difference between groups for prone-plank hold times ($U = 225$, $P = .98$) and side-plank hold times ($U = 134$, $P = .60$). Correlations for the dependent variables are displayed in Table 3. We found moderate to strong correlations between peak and mean throwing velocities per kilogram of BW and

the chop (peak: $r = 0.70$, $P = .001$; mean: $r = 0.64$, $P = .001$) and lift (peak: $r = 0.73$, $P = .001$; mean: $r = 0.58$, $P = .002$) outputs. We found small and moderate correlations between peak and mean throwing velocities per kilogram of BW and the prone-plank (peak: $r = 0.31$, $P = .007$; mean: $r = 0.50$, $P = .006$) and side-plank (peak: $r = 0.39$, $P = .001$; mean: $r = 0.47$, $P = .02$) hold times.

Table 2. Preintervention and Postintervention Results by Group

| Dependent Variable | Mean \pm SD | | | | Group Change Score ^a | | |
|--|--------------------|--------------------|--------------------|--------------------|---------------------------------|-----------------|---------------------|
| | Endurance Training | | Power Stability | | Endurance Training | Power Stability | P Value |
| | Preintervention | Postintervention | Preintervention | Postintervention | | | |
| Peak throwing velocity, km/h | 108.62 \pm 18.61 | 108.30 \pm 18.81 | 108.30 \pm 21.41 | 113.71 \pm 21.41 | -0.31 \pm 0.48 | 5.41 \pm 1.73 | <.001 ^b |
| Peak throwing velocity, km/h/kg of body weight | 1.36 \pm 0.16 | 1.33 \pm 0.16 | 1.44 \pm 0.14 | 1.52 \pm 0.14 | -0.03 \pm 0.01 | 0.08 \pm 0.03 | <.001 ^b |
| Mean throwing velocity, km/h | 104.20 \pm 18.50 | 106.83 \pm 18.82 | 105.81 \pm 21.42 | 111.81 \pm 21.31 | 2.61 \pm 2.51 | 6.00 \pm 2.81 | <.001 ^b |
| Mean throwing velocity, km/h/kg of body weight | 1.31 \pm 0.16 | 1.33 \pm 0.16 | 1.41 \pm 0.14 | 1.49 \pm 0.14 | 0.02 \pm 0.03 | 0.08 \pm 0.03 | <.001 ^b |
| Chop output, W | 536 \pm 202 | 557 \pm 199 | 511 \pm 206 | 616 \pm 224 | 20 \pm 78 | 105 \pm 68 | <.001 ^b |
| Chop output/kg of body weight, W | 6.50 \pm 2.12 | 6.61 \pm 2.12 | 6.60 \pm 2.12 | 8.01 \pm 2.22 | 0.22 \pm 0.91 | 1.32 \pm 0.91 | <.001 ^b |
| Lift output, W | 258 \pm 126 | 308 \pm 118 | 248 \pm 128 | 362 \pm 166 | 49 \pm 62 | 114 \pm 73 | .003 ^{b,c} |
| Lift output/kg of body weight, W | 3.01 \pm 1.21 | 3.61 \pm 1.03 | 3.11 \pm 1.31 | 4.71 \pm 1.62 | 0.59 \pm 0.67 | 1.42 \pm 0.82 | <.001 ^b |
| Prone-plank hold time, s | 128 \pm 41 | 154 \pm 54 | 126 \pm 32 | 151 \pm 42 | 26 \pm 33 | 26 \pm 39 | .98 ^c |
| Side-plank hold time, s | 75 \pm 14 | 90 \pm 27 | 72 \pm 32 | 98 \pm 24 | 19 \pm 18 | 22 \pm 23 | .60 ^c |

^a Average change for postintervention data minus preintervention data.

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

^c Indicates independent-sample Mann-Whitney U test.

DISCUSSION

Our results support the hypothesis that a 7-week power strength- and stability-training intervention would enhance the sport-specific muscle contributions of the proximal segments, resulting in improved throwing velocity among Division III softball and baseball players compared with a muscular-endurance-training protocol. The most important finding of our study was that the improvements in throwing velocity and in power assessments of the chop and lift maneuvers occurred simultaneously. The novel sport-specific training approach and comprehensive assessment techniques appear to be appropriate for monitoring the muscles that support the proximal segments and their contributions to sport performance. Incorporating muscular-power and -endurance assessments after power-stability- and endurance-training protocols allowed us to account for the sport-specific contributions of the proximal segments and their effects on sport performance. To our knowledge, no one has reported a simultaneous improvement in a muscular-power assessment that challenges the proximal segments and a sport-specific power skill, such as throwing velocity.

Before this study, research showing that improvements at the proximal segments translate into improved sport performance was limited. In the current intervention literature, investigators have not trained their participants for sport-specific function and have commonly used assessment techniques that focus on muscular endurance but do not account for changes in muscular strength or power. Several authors have exclusively used muscular-

endurance stability training and assessment protocols to detect change in sport skills that require muscular power.^{6,21–23} In some cases, the isometric-training interventions have matched those of the assessment techniques used to evaluate improvement in performance.^{6,21–23} Researchers have reported improved muscular-endurance isometric planks or a version of a static hold test after a training intervention that contained isometric static plank holds exclusively.^{9,18,22,23} The limitation with this approach is that isometric tasks are often not specific to a sport and are rarely replicated in sport-related activities. Thus, improvements in muscular endurance noted in the literature and in our study are likely training effects exclusive to the training stimulus and, therefore, cannot account for improved sport performance.^{16,18,21}

In addition, various static-plank assessments have been reported to have a learning effect, suggesting that a minimum of 2 familiarization periods may be necessary before testing to account for a true change in performance.^{6,29} Often, researchers do not provide ample familiarization before testing, which leads to ambiguous outcomes. We provided participants with 2 familiarization sessions for all dependent variables to control for a learning effect. Furthermore, our comprehensive assessment accounted for changes in the endurance and power contributions of the muscles that support the proximal segments while monitoring change in sport. Thus, our data indicated that the change at the proximal segments resulted in a faster throwing velocity.

Several authors have reported low correlations between power sport skills and endurance isometric assessments of

Table 3. Correlation Coefficients (P Values) for Throwing Velocity and Performance-Dependent Variables at Postintervention

| Dependent Variable (N = 46) | Mean Throwing Velocity/kg Body Weight, km/h | Chop Output/kg Body Weight, W | Lift Output/kg Body Weight, W | Prone-Plank Hold Time, s | Side-Plank Hold Time, s |
|---|---|-------------------------------|-------------------------------|--------------------------|--------------------------|
| Peak throwing velocity/kg body weight, km/h | 0.99 (.001) ^a | 0.70 (.001) ^a | 0.73 (.001) ^a | 0.31 (.007) ^a | 0.39 (.001) ^a |
| Mean throwing velocity/kg body weight, km/h | 1 | 0.64 (.001) ^a | 0.58 (.002) | 0.50 (.006) ^a | 0.47 (.02) ^a |
| Chop output/kg body weight, W | | 1 | 0.81 (.001) ^a | 0.45 (.002) ^a | 0.29 (.04) ^a |
| Lift output/kg body weight, W | | | 1 | 0.22 (.15) | 0.23 (.13) |
| Prone-plank hold time, s | | | | 1 | 0.58 (.001) ^a |
| Side-plank hold time, s | | | | | 1 |

^a Indicates correlation ($P < .05$).

the proximal segments.^{6,30} The chop and lift assessments have been reported to have low correlations with the Biering-Sørensen test (r range = $-0.02, 0.01$) and low to moderate correlations with isometric side planks (r range = $0.36-0.59$). Similar to the muscular-endurance plank tests, the Biering-Sørensen test is a maximal-endurance static-hold maneuver that requires a person to maintain an erect trunk position off the edge of a table while the lower extremities are secured.⁷ We used prone-plank and side-plank tests but not the Biering-Sørensen test; however, these tests have been reported to isolate the spinal stabilizers in a similar manner.⁴ Our data were similar to those of previous reports for the correlation between the prone-plank and lift tests (r range = $0.22-0.23$, $P > .13$) but not between the prone-plank and chop tests (r range = $0.29-0.45$, $P < .04$).⁷ Authors of the EMG literature have found that the prone-plank and Biering-Sørensen tests favor muscle-activation patterns for the anterior and posterior musculature of the lumbopelvic area, respectively.^{4,26} Although we did not monitor EMG activation, the comparison between our data and that of previous reports indicates that the chop and lift movements may predominately depend on the anterior and posterior lumbopelvic muscle groups, respectively. The low to moderate correlations in our study between the static planks and peak (r range = $0.31-0.39$) and mean (r range = $0.47-0.50$) throwing velocity suggest that sequential degrees of muscular stability and control are possibly necessary to complete ballistic movements, as McGill et al¹ reported. Using the chop and lift tests in tandem with the traditional isometric muscular-endurance planks provided a comprehensive assessment that allowed us to develop a sport-specific muscular profile of the proximal musculature.

One challenge in evaluating the current literature is the lack of reliable and valid assessment techniques to examine power outputs of the proximal segments.¹⁷ Shinkle et al³⁰ recently reported moderate correlations (r range = $0.40-0.60$) between an explosive medicine-ball toss and explosive field tests, such as a 1RM squat and a 40-yd (36-m) dash. Thus, researchers have suggested that ballistic training and assessment techniques, such as plyometrics and weighted-ball toss, may be more appropriate in stressing the proximal musculature for movement patterns similar to those in power sports.^{1,30} We used the chop and lift 1RM power tests, which have been identified as reliable measures of muscular power that challenge the proximal segments in a manner similar to sport.⁷ The moderate to strong correlations between throwing velocity and the chop and lift tests (r range = $0.58-0.73$) are similar to those reported by Shinkle et al.³⁰ The shared variance between the skills indicates that the explosive nature and multi-planar action of the chop and lift movements mimic actions and muscular activity similar to those used in an overhead throw. However, this may not hold true for power-sport skills involving the lower extremity, such as kicking. Further investigation may be necessary to determine whether the nature of the movement patterns for the chop and lift tests are more appropriate for those skills that incorporate explosive actions with the upper extremity and not the lower extremity. Regardless, the sport-specific nature of chop and lift assessment tech-

niques offers information about the muscular-power contributions for sport rather than the muscular-endurance contributions.

Consistent with the literature, the ET group improved in muscular-endurance plank hold times but not in throwing velocity and power measures. The improvements in throwing velocity and the power measures for the PS group seem appropriate, as the exclusive difference between the ET and PS training programs was the muscular-strength and -power training. Training multi-planar diagonal movements with heavy resistance resulted in improved strength and power capabilities of the muscles that support the proximal segments and translated into improved throwing velocity. Isolating the proximal segments with both strength and power movements on stable and unstable training surfaces was likely to facilitate gains at the proximal segments, which can positively influence sport performance.^{12,22,23} Furthermore, the low volume of muscular-endurance training seems to have played a role in improving performance but likely had less influence on peak overhead throwing velocity. Endurance-training techniques have been reported to improve the muscular endurance of the deep spinal stabilizers, but little evidence exists that these gains translate into enhanced sport performance.^{16,17,21,22} The improvements in mean throwing velocity for both groups in our study indicated a potential increase in proximal stabilization gained from the training. Our data suggest that isometric endurance-training techniques are likely necessary and may contribute to both static and dynamic skills; however, more research is needed to better understand the quantity necessary for power-based skills. To our knowledge, we are the first to study participants performing sport-specific strength and power movements on stable and unstable surfaces and a small degree of endurance training on a stable surface.

The combined measures and novel training interventions appear to offer insight into the muscular contributions that rely primarily on static muscular endurance versus those that are strength or power contributors to the proximal stabilizers.⁷ Our data suggest that muscular-endurance and -strength or -power contributions from the proximal segments can affect the power movement of throwing velocity. Thus, a comprehensive assessment similar to the one we used will help clinicians evaluate the effectiveness of an intervention targeting the proximal segments for tasks that may be endurance based versus strength based or power based, as well as in determining volume and intensity dosage specific to a sport.

Our study had limitations. As is true in most intervention studies, the participants were not blinded to the intervention; however, the members of each group were strongly encouraged not to participate in additional strength training for the proximal segments. Although we found no signs of a contamination bias, a potential for some crossover existed because many of the athletes trained and resided in close proximity.

CONCLUSIONS

A sport-specific proximal synergy-training program for collegiate softball and baseball players resulted in

improvements in the muscles that support the proximal segments and throwing velocity. Our results indicated that combining sport-specific training stimuli that target the specific muscular-endurance, -strength, and -power contributions of the proximal segments contributed to performance improvements. A novel assessment, including muscular endurance and strength or power, will allow clinicians to obtain sport-specific muscular contributions of the proximal segments. Power-based sport skills, such as throwing, should focus on movements emphasizing strength or power resistance and a small degree of muscular-endurance training. Researchers should investigate the dosage effects for training the proximal segments for both power and endurance sport-performance outcomes.

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