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# Journal of Athletic Training

Volume 46 Number 2 March-April 2011

- *Hip-Abductor Strengthening for Patellofemoral Pain Syndrome*
- *Heat-Illness Screening Instrument*
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- *Prevention of Pediatric Overuse Injuries*

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# Journal of Athletic Training

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# Journal of Athletic Training

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## Original Research

### Clinical Studies



### Observational Studies



## Position Statement



## Departments

## *JAT* Manuscript Reviewers' Workshop

Sunday, June 19, 2011
New Orleans, LA

All current and future reviewers are invited to our sessions:

1) 3-4 PM: Senior Associate Editor Craig R. Denegar, PhD, ATC, PT, FNATA, will speak on providing helpful manuscript reviews, including an overview of the *JAT* review process and the components of a constructive review.

2) 4-6 PM: Editor-in-Chief Christopher D. Ingersoll, PhD, ATC, FNATA, FACSM, and the *JAT* Section Editors will introduce the concept of an evidence map for athletic training. Attendees will then participate in small-group discussions on various topics to be included in the evidence map.

To attend session 1, session 2, or both sessions, please RSVP to the Editorial Office (jathtr@mindspring.com, phone: 706-494-3345, fax: 706-494-3348).

We hope to see you there!

## CEU Quiz

The CEU quiz for the March–April 2011 issue
(Volume 46, Number 2) of the
***Journal of Athletic Training*** will be located
online at www.nata.org/quizcenter

## 34th Annual Undergraduate Student Writing Contest

**All materials must be received on or before March 1, 2012**

The electronic file is to be submitted to LLDewald@gmail.com and hard copy materials mailed to

NATA Undergraduate Student Writing Contest
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2952 Stemmons Freeway
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For questions about the contest, contact Dr Lori Dewald, EdD, ATC, CHES, F-AAHE, at LLDewald@gmail.com.

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# The Assessment of Airway Maneuvers and Interventions in University Canadian Football, Ice Hockey, and Soccer Players

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***Context:*** Managing an airway in an unconscious athlete is a lifesaving skill that may be made more difficult by the recent changes in protective equipment. Different airway maneuvers and techniques may be required to help ventilate an unconscious athlete who is wearing full protective equipment.

***Objective:*** To assess the effectiveness of different airway maneuvers with football, ice hockey, and soccer players wearing full protective equipment.

***Design:*** Crossover study.

***Setting:*** University sports medicine clinic.

***Patients or Other Participants:*** A total of 146 university varsity athletes, consisting of 62 football, 45 ice hockey, and 39 soccer players.

***Intervention(s):*** Athletes were assessed for different airway and physical characteristics. Three investigators then evaluated the effectiveness of different bag-valve-mask (BVM) ventilation techniques in supine athletes who were wearing protective equipment while inline cervical spine immobilization was maintained.

***Main Outcome Measure(s):*** The effectiveness of 1-person BVM ventilation (1-BVM), 2-person BVM ventilation (2-BVM), and inline immobilization and ventilation (IIV) was judged by each investigator for each athlete using a 4-point rating scale.

***Results:*** All forms of ventilation were least difficult in soccer players and most difficult in football players. When compared with 1-BVM, both 2-BVM and IIV were deemed more effective by all investigators for all athletes. Interference from the helmet and stabilizer were common reasons for difficult ventilation in football and ice hockey players.

***Conclusions:*** Sports medicine professionals should practice and be comfortable with different ventilation techniques for athletes wearing full equipment. The use of a new ventilation technique, termed *inline immobilization and ventilation*, may be beneficial, especially when the number of responders is limited.

***Key Words:*** emergency management, ventilation, resuscitation

**Key Points**

- Control of a patient's compromised airway may be affected by factors such as the sport and protective equipment, number of people able to assist, individuals' experience with different airway techniques and equipment, and physical attributes and size of the clinician.
- Sports medicine professionals should be familiar with more than one basic airway maneuver; in general, 2-person bag-valve-mask ventilation or inline immobilization and ventilation may be more effective than 1-person bag-mask-valve ventilation.
- Inline immobilization and ventilation may be preferable to 1-person bag-valve-mask ventilation when the clinician is tall or 2 people are not available.

Maintaining an airway and assisting breathing in an athlete wearing protective equipment who has become obtunded or unconscious is a challenging yet essential skill for any health care professional covering sporting events. Available options include simple airway procedures such as a jaw-thrust maneuver; placement of an oral airway to improve ventilation; adjunctive airway devices, such as a bag-valve-mask (BVM), laryngeal mask airway, or Combitube (Kendall Sheridan, Argyle, NY); and, finally, definitive airway control with endotracheal intubation.[1–3] In an unconscious athlete, maintaining an adequate airway and assisting ventilation is a time-sensitive but often difficult procedure that is potentially lifesaving.

Immobilization of the cervical spine often complicates airway management in an injured athlete because the cervical spine is ideally splinted in a neutral position. This is most often accomplished by positioning someone at the head of the supine athlete to hold the helmet or head in a neutral (inline) position. Unfortunately, this necessary procedure allows for less access to the airway, with less physical space for the athletic trainer or physician to maintain or control the airway at the head of the athlete. In football and ice hockey players, the helmet and shoulder pads are typically left in place to maintain neutral cervical spine alignment. If the helmet is removed, the head and neck usually fall into an extended position,[4–10] possibly further complicating an existing cervical spine injury.[11] As such, most experts agree that when a football or ice hockey player has sustained a possible cervical spine injury, either the helmet should be left in place while the face mask or visor is removed[2,3,12–17] or both helmet and shoulder pads should be removed simultaneously.[3]

As technology advances, sport equipment evolves. Recently, football and ice hockey helmets have become larger in an effort to provide more protection.[18,19] The outer shells of many helmets now extend to cover more of the face and jaw area, often obscuring the angle of the mandible. Inflatable bladders near the ears and side of the face inside newer football helmets allow for better fit and protection, but they are not easy to remove and can interfere with access to the angle of the mandible. Access to the angle of the mandible is important because most rescue airway maneuvers involve pulling the mandible anteriorly by the angle to allow for better airflow and ventilation. Shoulder pads also have been getting larger, sometimes encroaching on the jaw and neck area of an unconscious supine athlete. All of these changes may adversely affect airway management in the obtunded or unconscious athlete.

To our knowledge, we are the first to assess the effectiveness and practicality of different basic airway maneuvers in football, ice hockey, and soccer players who were wearing full protective equipment for their respective sports. By being aware of the potential hurdles to successful airway management in athletes and by having different BVM options, the sports medicine professional will be better prepared and will increase the chance of survival for the athlete.

## METHODS

McGill University has men's and women's varsity soccer teams, men's and women's varsity ice hockey teams, and a men's varsity football team. Different airway procedures and devices were tested in healthy volunteers from these 5 teams. Protective equipment around the head and neck area in soccer is minimal, so we decided that soccer players would function as a control group. This study was approved by the Ethics Review Board of the McGill University School of Medicine.

We collected consent and baseline information including age, height, mass, and sex from the volunteers. Athletes were excluded if they had experienced a head or neck injury precluding active participation with the team; had recent or current symptoms indicating an upper or lower respiratory tract infection (eg, fever, sore throat, rhinorrhea, cough, shortness of breath, increased sputum production); had active oral or labial lesions or injuries (eg, canker, cold sores); or had eaten a meal within 120 minutes of the study. Noninvasive measures of specific airway characteristics often used to predict ease or difficulty in airway control, described in detail elsewhere,[20–23] were taken. These included a Mallampati score (from 1 to 4), which assesses the posterior pharyngeal structures visualized with maximal mouth opening. A high Mallampati score (class 4) is associated with more difficult ventilation and endotracheal intubation.[24] Also assessed were the size of oral opening (ability to insert 3 of the athlete's own fingers between the teeth), hyomental distance (ability to accommodate at least 3 finger breadths between the hyoid bone and the mentum), and upper lip test (ability to place the lower teeth over upper lip), all of which, when present, predict easier ventilation and endotracheal intubation.[25] The presence of a beard or moustache, overbite, or false teeth was also assessed because any of these can also affect ventilation effectiveness. These baseline characteristics and airway measurements provide information on the sample studied and may allow for comparisons with participants in future airway studies.

After the airway assessment was completed, athletes in full protective sports equipment were placed in a supine position on their field of play: a FieldTurf (Calhoun, GA) surface for soccer and football and the ice or hallway beside the ice surface for ice hockey. Data collection was usually done during or after practices, so that volunteers were in their own equipment and as sweaty as they might be during a game situation. The only substitution to the athletes' own protective equipment was that football players were asked to select and wear a properly fitting Riddell Revolution (Elyria, OH) helmet with the face mask already removed, whereas the ice hockey players were asked to select and wear a properly fitting Bauer (Mississauga, ON, Canada) helmet with the face mask/visor already removed. Although the usual standard of care for helmeted athletes with a possible cervical spine injury is to leave the chin strap in place, we undid or removed the chin straps because they interfere with access to the angle of the mandible and proper placement of the facial mask of the BVM device. The supine athlete then had his or her head and cervical spine immobilized by a physician, athletic trainer, or athletic therapist experienced with cervical immobilization. To ensure as uniform a cervical spine immobilization technique as possible, the most senior athletic trainer or athletic therapist involved with the sports teams reviewed the technique before the study. The physician, athletic trainer, or athletic therapist immobilized the head and cervical spine in the standard kneeling position at the head of the athlete by grasping both sides of the head or helmet, allowing himself or herself to stay at the top of the head or slightly off to the side.

The different BVM situations were assessed by 3 investigators with different clinical experiences and physical attributes. Investigator A (height = 170 cm, mass = 75 kg) was a recent male graduate in emergency medicine. Investigator B (height = 166 cm, mass = 62 kg) was a female athletic therapist with more than 15 years' experience covering football and ice hockey. Investigator C (height = 185 cm, mass = 95 kg) was a male emergency and sports medicine physician with more than 13 years' work experience. We felt that having 3 individuals with different airway experiences and physical attributes would help to imitate the range of experiences and sizes of sports medicine professionals called upon to maintain airways in emergency situations.

Three BVM ventilation positions were assessed in a supine athlete with his or her head and neck maintained in a neutral position by a physician, athletic trainer, or athletic therapist. The positions were as follows:

a) One-person BVM ventilation (1-BVM). Each investigator attempted to place the BVM device in proper position by himself or herself. This involves holding the

**Figure 1. Investigator A attempting 1-bag-valve-mask ventilation while inline immobilization of the cervical spine is maintained.**

jaw, usually at the angle of the mandible with one hand, and thrusting it forward while holding the BVM device over the mouth with the same hand (usually the left). The other hand (usually the right) is typically used to pump the bag (Figure 1). However, the bag was not pumped in this study.

b) Two-person BVM ventilation (2-BVM). One investigator used both hands to control the jaw and maintain the mask over the mouth while a second investigator held the bag and would pump the bag in an actual emergency (Figure 2).

c) Inline immobilization and ventilation (IIV). This technique involved each investigator crouching behind and to the left side of the person maintaining the inline immobilization and attempting to place the BVM in proper position by himself or herself. Again, this involves holding the jaw, usually at the angle of the mandible, and thrusting it forward while holding the mask over the mouth with the same hand (usually the left), so the other hand can pump the bag. The arm of the hand holding the bag in this position is placed around and over the head of the person maintaining the inline immobilization of the cervical spine (Figure 3). This technique has not been described elsewhere in a review of the literature (PubMed, 1962–2009) or in our inquiries with other health care and sports medicine professionals.

**Figure 2. Investigators A and C attempting 2-bag-valve-mask ventilation while inline immobilization of the cervical spine is maintained.**

**Figure 3. Investigator C attempting inline immobilization and ventilation while inline immobilization of the cervical spine is maintained.**

The adequacy or effectiveness of each BVM situation was judged by each investigator in each situation. We developed a scale for this study because no similar research had been conducted in these circumstances. Adequacy was quantified using a simple 4-point scale and assessed the seal of the facial mask, the ability to grasp the angle of the mandible, the ability to pull the jaw forward, and the ability to hold the ventilation bag when necessary:

3 = very good likelihood of ventilating
2 = fairly good likelihood of ventilating
1 = difficulty predicted in ventilation
0 = inability to ventilate predicted

When the investigator did not judge the effectiveness of the different BVM scenarios to be a 3, he or she was asked to list the reasons for difficulty with the technique being attempted.

To determine reproducibility of results for each rater, intrarater reliability was evaluated using the weighted $\kappa$ statistic. Kappa is a measure of the level of agreement that can be attributed to the reproducibility of the observations, rather than to chance agreement. Weighted $\kappa$ is a modification that uses weights to quantify the relative differences between categories and is more appropriate for ordinal scales such as the one used here.[26] We computed linearly weighted $\kappa$ values and 95% confidence intervals

**Table 1. Player and Airway Characteristics**

| Characteristic | Sport | | |
|---|---|---|---|
| | Football (n = 62) | Ice Hockey (n = 45) | Soccer (n = 39) |
| Age, y | 20.4 ± 1.7 | 21.6 ± 2.0 | 19.9 ± 2.0 |
| Height, cm | 181.0 ± 13 | 173.6 ± 11.9 | 171.4 ± 11.8 |
| Mass, kg | 95.0 ± 16.5 | 78.5 ± 12.4 | 69.8 ± 8.9 |
| Males, n (%) | 62 (100.0) | 26 (57.8) | 20 (51.3) |
| Female, n (%) | 0 (0.0) | 19 (42.2) | 19 (48.7) |
| Mallampati score, n (%) | | | |
| 1 | 36 (58.1) | 20 (45.5)[a] | 17 (43.6) |
| 2 | 15 (24.2) | 14 (31.8)[a] | 9 (23.1) |
| 3 | 6 (9.7) | 9 (20.5)[a] | 9 (23.1) |
| 4 | 5 (8.1) | 1 (2.3)[a] | 4 (10.3) |
| Hyomental distance, n (%) | | | |
| <3 fingers | 1 (1.6) | 9 (20.5)[a] | 7 (17.9) |
| ≥3 fingers | 61 (98.4) | 35 (79.5)[a] | 32 (82.1) |
| Mouth opening, n (%) | | | |
| <3 fingers | 0 (0.0) | 2 (4.6)[a] | 1 (2.6) |
| Upper lip test, n (%) | | | |
| Favorable | 42 (67.7) | 33 (75.0)[a] | 31 (79.5) |
| Unfavorable | 20 (32.3) | 11 (25.0)[a] | 8 (20.5) |
| Facial hair, n (%) | | | |
| Absent | 31 (50.0) | 39 (88.6)[a] | 30 (76.9) |
| Present (eg, beard, goatee) | 31 (50.0) | 5 (11.4)[a] | 9 (23.1) |
| Dentition, n (%) | | | |
| Normal | 50 (80.7) | 34 (79.1)[b] | 35 (89.7) |
| Abnormal (eg, buck teeth, false teeth) | 12 (19.3) | 9 (20.9)[b] | 4 (10.3) |

[a] Data missing for 2 athletes.
[b] Data missing for 1 athlete.

using the approach and FORTRAN program of Mielke et al[27] for each scale and rater by sport on a subset of randomly selected athletes. Each athlete was assessed 3 times by the same practitioner. The results for the weighted κ values are listed in the Appendix and show substantial agreement or higher.[28] In all instances, we observed good agreement; the few disagreements involved a 1-point difference. We know,[28] however, that κ can sometimes be unreliable when complete agreement is observed or a rare disagreement occurs within a set of nearly identical values because κ depends on the prevalence of each category. Thus, κ may not be reliable for these rare observations. This situation occurred in our data when, within a particular scale and rater, all value points were identical, or identical save for one. In order to provide a picture of the reproducibility of the scales within each rater when this occurred, we report percentage agreement values and 95% confidence intervals. All descriptive statistics were computed using SAS software (version 9.2; SAS Institute Inc, Cary, NC).

**Table 2. Combined Investigators' and Individual Investigator's Assessments of 1-Person Bag-Valve-Mask Ventilation Airway Maneuver[a]**

| Sport | Investigator(s) | Technique Assessment (4-Point Scale)[b] | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Football | Combined | 2 | 59 | 98 | 27 |
| | A | 0 | 9 | 46 | 7 |
| | B | 2 | 9 | 31 | 20 |
| | C | 0 | 41 | 21 | 0 |
| Ice hockey | Combined | 0 | 8 | 75 | 52 |
| | A | 0 | 2 | 19 | 24 |
| | B | 0 | 4 | 22 | 19 |
| | C | 0 | 2 | 34 | 9 |
| Soccer | Combined | 0 | 0 | 19 | 98 |
| | A | 0 | 0 | 6 | 33 |
| | B | 0 | 0 | 5 | 34 |
| | C | 0 | 0 | 8 | 31 |

[a] Each investigator attempted each maneuver once, so the total attempts were 186 for football, 135 for ice hockey, and 117 attempts for soccer.
[b] Scoring: 3 = very good likelihood of ventilating, 2 = fairly good likelihood of ventilating, 1 = difficulty predicted in ventilation, 0 = inability to ventilate predicted.

Table 3. Combined Investigators' and Individual Investigator's Assessments of 2-Person Bag-Valve-Mask Ventilation Airway Maneuver[a]

| Sport | Investigator(s) | Technique Assessment (4-Point Scale)[b] | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Football | Combined | 1 | 10 | 96 | 79 |
| | A | 0 | 0 | 30 | 32 |
| | B | 1 | 2 | 18 | 41 |
| | C | 0 | 8 | 48 | 6 |
| Ice hockey | Combined | 0 | 0 | 4 | 131 |
| | A | 0 | 0 | 1 | 44 |
| | B | 0 | 0 | 2 | 43 |
| | C | 0 | 0 | 1 | 44 |
| Soccer | Combined | 0 | 0 | 0 | 117 |
| | A | 0 | 0 | 0 | 39 |
| | B | 0 | 0 | 0 | 39 |
| | C | 0 | 0 | 0 | 39 |

[a] Each investigator attempted each maneuver once, so the total attempts were 186 for football, 135 for ice hockey, and 117 attempts for soccer.
[b] Scoring: 3 = very good likelihood of ventilating, 2 = fairly good likelihood of ventilating, 1 = difficulty predicted in ventilation, 0 = inability to ventilate predicted.

## RESULTS

At the beginning of the 2007 season, there were 74 football players, 52 ice hockey players, and 44 soccer players on the varsity teams. Due to absences on the days of recruitment and attrition, 62 athletes were fully recruited for football, 45 for ice hockey, and 39 for soccer. Their baseline and airway characteristics are listed in Table 1. Combined and individual investigator assessments of difficulty of each airway maneuver are listed in Tables 2 through 4. Combined investigator assessments of the different airway maneuvers as a percentage of the total for each sport are shown in Figures 4 through 6. Difficulties for each situation are listed in Tables 5 through 7.

When the 1-BVM assessment was not a 3, we assumed that 2-BVM and IIV would offer improvements over standard 1-BVM ventilation. For football players, after switching from 1-BVM to 2-BVM, the assessment improved by at least 1 point 64.2% (102/159) of the time. Investigator A improved 36 of 55 attempts, investigator B improved 29 of 42 attempts, and investigator C improved 37 of 62 attempts. For ice hockey players, the assessment improved at least 1 point 95.2% (79/83) of the time (20 of 21 attempts for investigator A, 24 of 26 attempts for investigator B, and 35 of 36 attempts for investigator C). For soccer players, switching to 2-BVM improved the assessment by at least 1 point 100% (19/19) of the time. Similarly, switching from 1-BVM to IIV frequently changed the assessment by at least 1 point. For football players, the assessment improved at least 1 point after switching from 1-BVM to IIV 59.1% (94 of 159 attempts) of the time. Investigator A improved 18 of 55 attempts, investigator B improved 26 of 42 attempts, and investigator C improved 50 of 62 attempts. For ice hockey players, switching from 1-BVM to IIV improved the assessment 79.5% (66/83) of the time (15 of 21 attempts for investigator A, 17 of 26 attempts for investigator B, and 34 of 36 attempts for investigator C). For soccer players, switching to IIV improved the assessment by at least 1 point 94.7% (18 of 19 attempts) of the time (6 of 6 attempts for investigator A, 5 of 5 attempts for investigator B, and 7 of 8 attempts for investigator C).

## DISCUSSION

Our results reveal general trends and the individual variability of investigator success in airway management using 3 basic airway maneuvers. Overall, with the basic airway maneuvers (1-BVM, 2-BVM, IIV), soccer players

Table 4. Combined Investigators' and Individual Investigator's Assessments of Inline Immobilization and Ventilation Airway Maneuver[a]

| Sport | Investigator(s) | Technique Assessment (4-Point Scale)[b] | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 2 | 3 |
| Football | Combined | 0 | 5 | 105 | 76 |
| | A | 0 | 3 | 43 | 16 |
| | B | 0 | 2 | 18 | 42 |
| | C | 0 | 0 | 44 | 18 |
| Ice hockey | Combined | 0 | 5 | 24 | 106 |
| | A | 0 | 2 | 11 | 32 |
| | B | 0 | 3 | 11 | 31 |
| | C | 0 | 0 | 2 | 43 |
| Soccer | Combined | 0 | 0 | 1 | 116 |
| | A | 0 | 0 | 0 | 39 |
| | B | 0 | 0 | 0 | 39 |
| | C | 0 | 0 | 1 | 38 |

[a] Each investigator attempted each maneuver once, so the total attempts were 186 for football, 135 for ice hockey, and 117 attempts for soccer.
[b] Scoring: 3 = very good likelihood of ventilating, 2 = fairly good likelihood of ventilating, 1 = difficulty predicted in ventilation, 0 = inability to ventilate predicted.

Table 5. **Combined Investigators' and Individual Investigator's Reasons for Difficulties With 1-Person Bag-Valve-Mask Ventilation Airway Maneuver**[a]

| | | Reason for Difficulty | | | | |
|---|---|---|---|---|---|---|
| Sport | Investigator(s) | Angle of Jaw | Stabilizer | Helmet | Hands Too Small | Unable to Determine |
| Football | Combined | 9 | 65 | 147 | 0 | 0 |
| | A | 4 | 5 | 55 | 0 | 0 |
| | B | 5 | 3 | 41 | 0 | 0 |
| | C | 0 | 57 | 51 | 0 | 0 |
| Ice hockey | Combined | 21 | 52 | 14 | 2 | 2 |
| | A | 6 | 11 | 5 | 0 | 1 |
| | B | 12 | 8 | 4 | 2 | 1 |
| | C | 3 | 33 | 5 | 0 | 0 |
| Soccer | Combined | 10 | 7 | NA | 1 | 0 |
| | A | 5 | 1 | NA | 1 | 0 |
| | B | 4 | 0 | NA | 0 | 0 |
| | C | 1 | 6 | NA | 1 | 0 |

Abbreviation: NA, not applicable.

[a] Each investigator attempted each maneuver once, so the total attempts were 186 for football, 135 for ice hockey, and 117 for soccer.

were the least difficult to ventilate. Although ice hockey players were more difficult to ventilate than soccer players, football players were the most difficult for all 3 investigators to ventilate. In all sports and for all investigators, switching from 1-BVM to 2-BVM or IIV usually improved the assessment of airway maneuvers (Figures 4 through 6).

All 3 investigators listed stabilizer interference as a common cause of difficulty in 1-BVM in both football (65 of 186 attempts, 34.9%) and ice hockey (52 of 135 attempts, 38.5%) players, but helmet interference in football players caused the most problems. The helmet was listed as a cause for difficulty with 1-BVM in only 14 of 135 (10.4%) attempts in ice hockey, compared with 147 of 186 (79.0%) attempts in football. The newer football helmets have nonremovable air bladders at the jaw and ear and a hard shell that now covers more area along the jaw, which may make it more difficult to adequately grasp the angle of the mandible for airway control. These newer helmets have proven to be more effective at reducing concussions,[18] but sports medicine professionals should be aware that they may cause more difficulty in maintaining an airway in an emergency situation. Although switching from 1-BVM to 2-BVM or IIV almost eliminated the helmet as a cause of difficulty in ice hockey players, it remained a common problem in football players.

Individually, each investigator had specific difficulties with certain techniques and certain athletes. Not all athletes were rated the same by all investigators for the different BVM scenarios, as evidenced by the different subtotals for each investigator listed in Tables 2 through 4. The tallest investigator (investigator C) listed stabilizer interference as a cause of difficulty more often than the other investigators, especially for 1-BVM. Longer arms may make it more challenging for the sports medicine professional to position his or her arms in the limited space due to the presence of the person providing inline immobilization. The wrist and hand are forced into a more flexed and awkward position when attempting to hold the angle of the jaw (Figure 7). This flexed-wrist position is eliminated in the IIV positioning and, thus, investigator C was most aided by switching from 1-BVM to IIV. Conversely, the arms of the shorter investigators (A and B) were occasionally not long enough to comfortably reach around the stabilizer to ventilate the bag during IIV.

In an athlete who is not breathing, time is essential and only a few minutes are available to reestablish ventilation

Table 6. **Combined Investigators' and Individual Investigator's Reasons for Difficulties With 2-Person Bag-Valve-Mask Ventilation Airway Maneuver**[a]

| | | Reason for Difficulty | | | |
|---|---|---|---|---|---|
| Sport | Investigator(s) | Angle of Jaw | Stabilizer | Helmet | Unable to Determine |
| Football | Combined | 2 | 36 | 92 | 1 |
| | A | 0 | 1 | 29 | 1 |
| | B | 2 | 0 | 20 | 0 |
| | C | 0 | 35 | 43 | 0 |
| Ice hockey | Combined | 1 | 0 | 3 | 0 |
| | A | 0 | 0 | 1 | 0 |
| | B | 1 | 0 | 1 | 0 |
| | C | 0 | 0 | 1 | 0 |
| Soccer | Combined | 0 | 0 | NA | 0 |
| | A | 0 | 0 | NA | 0 |
| | B | 0 | 0 | NA | 0 |
| | C | 0 | 0 | NA | 0 |

Abbreviation: NA, not applicable.

[a] Each investigator attempted each maneuver once, so the total attempts were 186 for football, 135 for ice hockey, and 117 for soccer.

Table 7. Combined Investigators' and Individual Investigator's Reasons for Difficulties With Inline Immobilization and Ventilation Airway Maneuver[a]

| Sport | Investigator(s) | Reason for Difficulty | | | | | |
|---|---|---|---|---|---|---|---|
| | | Angle of Jaw | Stabilizer | Helmet | Arms Too Short | Hands Too Small | Unable to Determine |
| Football | Combined | 1 | 1 | 96 | 10 | 0 | 2 |
| | A | 0 | 0 | 37 | 8 | 0 | 1 |
| | B | 1 | 0 | 17 | 2 | 0 | 0 |
| | C | 0 | 1 | 42 | 0 | 0 | 1 |
| Ice hockey | Combined | 4 | 4 | 1 | 17 | 3 | 0 |
| | A | 1 | 2 | 0 | 10 | 0 | 0 |
| | B | 2 | 2 | 0 | 7 | 3 | 0 |
| | C | 1 | 0 | 1 | 0 | 0 | 0 |
| Soccer | Combined | 1 | 0 | NA | 0 | 0 | 0 |
| | A | 0 | 0 | NA | 0 | 0 | 0 |
| | B | 0 | 0 | NA | 0 | 0 | 0 |
| | C | 1 | 0 | NA | 0 | 0 | 0 |

Abbreviation: NA, not applicable.

[a] Each investigator attempted each maneuver once, so the total attempts were 186 for football, 135 for ice hockey, and 117 for soccer.

and oxygenation before permanent sequelae occur. Proponents of fully removing the helmet (and possibly shoulder pads) in an airway emergency may correctly point out how often interference from the helmet was listed as a cause for difficulty in BVM ventilation, but sports medicine professionals should know that removing a helmet and shoulder pads takes time and people, neither of which may be available in an airway emergency. Also, removing or cutting equipment may not always improve airway access as much as anticipated. This point was underscored in soccer players: not all soccer players were rated a 3 for 1-BVM, and switching to a 2-BVM or IIV did improve the effectiveness of ventilation in all but 1 case. Thus, switching to a different airway maneuver may provide a more rapid improvement in ventilation than removing equipment.

## LIMITATIONS

Several limitations were present in this study. First, the helmeted athletes already had their face masks or visors removed. An unconscious athlete who is wearing a helmet and face mask will require immediate airway intervention, such as removal of a mouthguard and a jaw-thrust maneuver before or during face-mask removal. Removing a face mask also takes time, and as indicated previously,[29] can be rife with its own complications and delays.

Only 3 investigators were studied, which limits the generalization of the results to all sports medicine professionals. Although the investigators were blinded to the results of the other investigators during 1-BVM and IIV assessments, they could not be blinded to other investigators' opinions on 2-BVM when 2 investigators were required to perform the intervention.

The scales used are surrogates for actual successful BVM ventilation. The players were not ventilated in the study and, as such, adequate oxygenation and ventilation cannot be guaranteed by a higher score on our scale. We can hypothesize that those athletes with higher scores on our scale would be more likely to have successful BVM

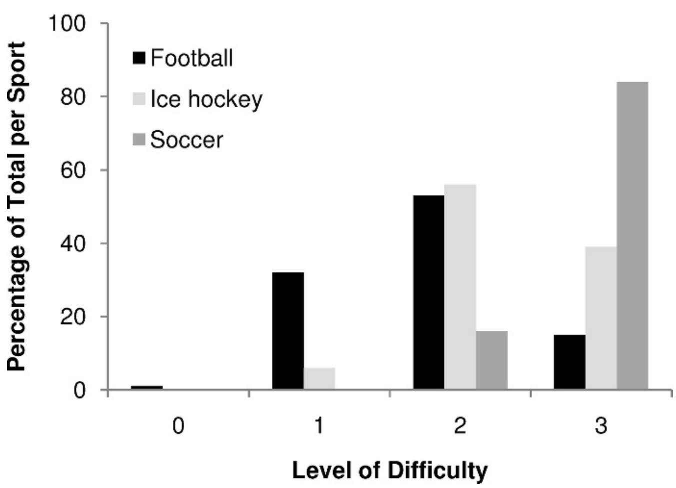


**Figure 4. Combined investigators' assessments of 1-bag-valve-mask ventilation. The assessments of investigators A, B, and C are combined for each sport. The sum of the technique assessments is 100%. Technique assessment: 3 = very good likelihood of ventilating, 2 = fairly good likelihood of ventilating, 1 = difficulty predicted in ventilation, 0 = inability to ventilate predicted.**

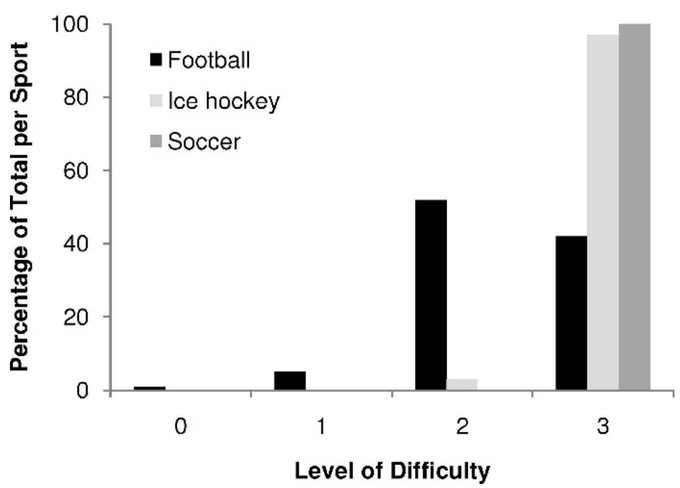


**Figure 5. Combined investigators' assessments of 2-bag-valve-mask ventilation. The assessments of investigators A, B, and C are combined for each sport. The sum of the technique assessments is 100%. Technique assessment: 3 = very good likelihood of ventilating, 2 = fairly good likelihood of ventilating, 1 = difficulty predicted in ventilation, 0 = inability to ventilate predicted.**

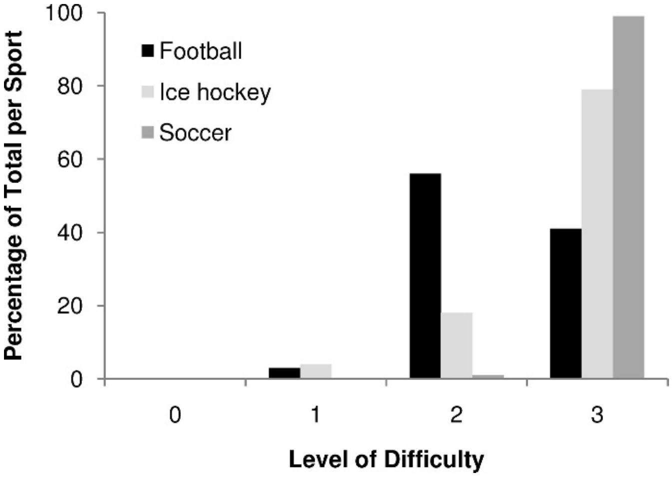


**Figure 6. Combined investigators' assessments of inline immobilization and ventilation. The assessments of investigators A, B, and C are combined for each sport. The sum of the technique assessments is 100%. Technique assessment: 3 = very good likelihood of ventilating, 2 = fairly good likelihood of ventilating, 1 = difficulty predicted in ventilation, 0 = inability to ventilate predicted.**

ventilation, but the possibility exists that actual BVM ventilation in the unconscious athlete may not be effective. The scale we used is new, and even though we calculated weighted κ values and percentage agreement for intrarater variability, we did not do the same for interrater variability because we assumed that individual investigators would have different success with different BVM scenarios, given their different skill sets and physical attributes. We believe this to be one of the important findings of the research: Each sport medicine professional may have his or her own difficulties with an individual BVM technique and must be prepared to alter the technique if needed. The weighted κ values and percentage agreement for intrarater variability were calculated using only a portion of the sample due to the limited numbers of athletes available and, therefore, may account for the wide confidence intervals for each individual rater for each sport and airway maneuver.

The helmets tested were the models most commonly worn by each team, yet only one model each of football and ice hockey helmets was used in this study. It is possible that different makes and models of helmets would be associated with less difficulty or different types of problems.

## CONCLUSIONS

Sports medicine professionals should be aware that control of a compromised airway may be affected by many factors, including the sport and the protective equipment used, the number of people able to assist, the experience of the individual with different airway techniques and equipment, and likely the physical attributes and size of the physician, athletic trainer, or athletic therapist. Clinicians should become familiar with more than one basic airway maneuver, remembering that 2-BVM and IIV may be more effective in most circumstances than traditional 1-BVM. When necessary, especially for taller sports medicine professionals, IIV may be a better alternative to 1-BVM, particularly if numbers do not allow for 2-BVM.

**Figure 7. Investigator C attempting 1-bag-valve-mask ventilation while inline immobilization of the cervical spine is maintained. Notice how the left wrist must be placed in a more flexed position due to limited space available for the left arm.**


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**Appendix. Intrarater Weighted κ Values and Percentage of Agreement for the Airway Maneuvers (95% Confidence Intervals)[a]**

| Airway Maneuver | Investigator | Football (n = 11)[b] | Hockey (n = 9)[b] | Soccer (n = 10)[b] |
|---|---|---|---|---|
| 1-person bag-valve-mask | A | 0.72 (0.46, 0.98) | 0.79 (0.50, 1.0) | 0.85 (0.48, 1.0) |
| | B | 0.84 (0.57, 1.0) | 0.74 (0.46, 1.0) | 0.69 (0.33, 1.0) |
| | C | 0.83 (0.56, 1.0) | 0.90 (0.60, 1.0) | 0.81 (0.44, 1.0) |
| 2-person bag-valve-mask | A | 0.80 (0.51, 1.0) | 0.67 (0.29, 1.0) | 0.93[c] (0.79, 0.98) |
| | B | 0.76 (0.47, 1.0) | 0.65 (0.26, 1.0) | 0.93[c] (0.79, 0.98) |
| | C | 0.88 (0.56, 1.0) | 0.84 (0.45, 1.0) | 0.93[c] (0.79, 0.98) |
| Inline immobilization and ventilation | A | 0.72 (0.42, 1.0) | 0.74 (0.40, 1.0) | 1.0[c] (0.89, 1.0) |
| | B | 0.78 (0.46, 1.0) | 0.73 (0.39, 1.0) | 0.93[c] (0.79, 0.98) |
| | C | 0.77 (0.42, 1.0) | 0.81 (0.42, 1.0) | 1.0[c] (0.89, 1.0) |

[a] Interpretation of weighted κ is as follows[28]: <0, less than chance agreement; 0.01–0.20, slight agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, substantial agreement; 0.81–0.99, almost-perfect agreement; 1.0, perfect agreement.

[b] The number of athletes in each group is a subset of randomly selected athletes from the larger groups. These subsets were used to calculate intrarater reliability.

[c] Total agreement occurred for each individual rater (rating = 3) and one instance of 1-point disagreement for each rater (rating = 2). Kappa returned no value due to the very small prevalence of the ratings of 0, 1, and 2. In these instances, average percentage of agreement was used.

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# Arthrometric Measurement of Ankle-Complex Motion: Normative Values

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***Context:*** Valid and reliable measurements of ankle-complex motion have been reported using the Hollis Ankle Arthrometer. No published normative data of ankle-complex motion obtained from ankle arthrometry are available for use as a reference for clinical decision making.

***Objective:*** To describe the distribution variables of ankle-complex motion in uninjured ankles and to establish normative reference values for use in research and to assist in clinical decision making.

***Design:*** Descriptive laboratory study.

***Setting:*** University research laboratory.

***Patients or Other Participants:*** Both ankles of 50 men and 50 women (age = 21.78 ± 2.0 years [range, 19–25 years]) were tested.

***Intervention(s):*** Each ankle underwent anteroposterior (AP) and inversion-eversion (I-E) loading using an ankle arthrometer.

***Main Outcome Measure(s):*** Recorded anterior, posterior, and total AP displacement (millimeters) at 125 N and inversion, eversion, and total I-E rotation (degrees) at 4 Nm.

***Results:*** Women had greater ankle-complex motion for all variables except for posterior displacement. Total AP displacement of the ankle complex was 18.79 ± 4.1 mm for women and 16.70 ± 4.8 mm for men ($U = 3742.5$, $P < .01$). Total I-E rotation of the ankle complex was 42.10° ± 9.0° for women and 34.13° ± 10.1° for men ($U = 2807$, $P < .001$). All variables were normally distributed except for anterior displacement, inversion rotation, eversion rotation, and total I-E rotation in the women's ankles and eversion rotation in the men's ankles; these variables were skewed positively.

***Conclusions:*** Our study increases the available database on ankle-complex motion, and it forms the basis of norm-referenced clinical comparisons and the basis on which quantitative definitions of ankle pathologic conditions can be developed.

***Key Words:*** normal distribution, flexibility

**Key Points**

- This study increases the available database on ankle-complex motion and forms the basis of norm-referenced clinical comparisons.
- Women had greater ankle range of motion than men, and all of the range-of-motion variables measured were normally distributed except for anterior displacement, inversion rotation, eversion rotation, and total inversion-eversion rotation, which showed a higher incidence toward hypermobility.
- Our findings are clinically important because they will assist in the clinical decision-making process, enabling comparisons to be made with individual patient data and enabling quantitative definitions of ankle conditions to be developed.

Instrumented ankle arthrometry allows the examiner to quantify ligamentous laxity in lieu of manual examination.[1–3] Valid and reliable measurements of the combined motions within the talocrural and subtalar joints (ankle complex) have been investigated fully and reported using the Hollis Ankle Arthrometer (Blue Bay Research, Inc, Navarre, FL).[3–6] Consisting of a 6-degrees-of-freedom spatial kinematic linkage, this device is described as a suitable evaluation tool that quantifies the anteroposterior (AP) load displacement and inversion-eversion (I-E) rotational characteristics of the ankle complex.[3,4,7]

The Hollis Ankle Arthrometer has been used in a variety of clinical and research settings involving college-aged athletes and participants less than 25 years of age. Researchers have applied this type of arthrometric assessment in studies to biomechanically assess ankle-complex laxity in vivo and in vitro,[3,4,8] identify ankle instability after injury,[9–13] investigate the effects of sex and athletic status on ankle-complex laxity,[14] identify the relationship between ankle and knee ligamentous laxity and generalized joint laxity,[15] investigate the effects of balance training on gait in patients with chronic ankle instability,[13] investigate the effects of limb dominance on ankle laxity,[4] and assess the effectiveness of ankle taping.[16]

One limitation of using the Hollis Ankle Arthrometer and of using instrumented ankle arthrometry in general is that relatively small sample sizes have been reported and no normative data are available for comparison and reference.[9–14] Kovaleski et al[4] investigated total AP displacement and I-E rotation between the dominant and nondominant ankles in a group of 41 male and female participants (age = 23.8 ± 4.4 years). Bilateral ankle comparisons showed no differences in ankle-complex laxity, and they reported mean total AP displacement of 18.47 ± 5.1 mm for the dominant ankle and 17.51 ± 5.4 mm for the nondominant ankle. They also reported mean total I-E rotation of 46.19° ± 12.2° for the dominant ankle and 47.38° ± 14.3° for the nondominant ankle. The relatively large SDs indicated sizable variations in AP displacement and I-E rotation measurements in the uninjured ankle. To establish normative data for ankle-complex motion, adequate sample size is important to describe the resulting distribution and to ensure confidence that the theoretical distribution fitted to the data has minimal error associated with it.

Given the importance of having normative values against which clinical findings can be compared, the purpose of our study was to describe the distribution variables of ankle-complex motion in uninjured ankles and to establish normative reference values for use in research and to assist in clinical decision making.

## METHODS

### Participants

Participants included 50 men (age = 21.9 ± 2.1 years, height = 178.2 ± 7.4 cm, mass = 86.9 ± 21.1 kg) and 50 women (age = 21.7 ± 2.0 years, height = 165.1 ± 7.9 cm, mass = 65.7 ± 11.1 kg) from 19 to 25 years of age (21.78 ± 2.0 years). Ninety-three participants were right-leg dominant, and 7 were left-leg dominant. The *dominant leg* was defined operationally as the leg used to kick a ball. None of the participants had a history of lower extremity injury, including ankle sprain. Before testing, all participants provided written informed consent, and the university's institutional review board approved the study.

Participants completed the Foot and Ankle Outcome Score (FAOS) questionnaire to gauge self-reported ankle function.[17] The FAOS is a subjective self-report of ankle function in daily activities, sports, and recreation that is divided into 5 subscales. A normalized score (100 indicating *no problems* and 0 indicating *extreme problems*) was calculated for each subscale. The results of the FAOS survey showed the FAOS subscale mean scores ranged from 95.2 ± 10.5 to 99.1 ± 3.0, which implied that the ankles included in our study were free of problems associated with ankle dysfunction.

### Instrumentation

Instrumented measurement of ankle-complex motion was conducted using the Hollis Ankle Arthrometer.[7] The arthrometer consists of a spatial kinematic linkage, an adjustable plate fixed to the foot, a load-measuring handle attached to the footplate through which the load is applied, and a reference pad attached to the tibia.[3,4] Ankle arthrometry is a method for assessing either translatory displacement or angular motion of the foot in relation to the leg that results from the combined motions within the talocrural and subtalar joints. The spatial kinematic linkage is a 6-degrees-of-freedom electrogoniometer that measures applied forces and moments and the resultant translations and rotations of the ankle complex.[2,7] The arthrometer spatial linkage connected the tibial pad to the footplate and measured the motion of the footplate relative to the tibial pad. Ankle-flexion angle was measured from the plantar surface of the foot relative to the anterior tibia and was determined by the 6-degrees-of-freedom electrogoniometer within the instrumented linkage. An Inspiron 1525 computer (Dell Inc, Round Rock, TX) with an analog-to-digital converter (National Instruments Corp, Austin, TX) was used to simultaneously record and calculate the data. The resulting AP displacement (millimeters) and I-E rotation (degrees of range of motion) along with the corresponding AP load and I-E torque were recorded. We used a custom software program written in LabVIEW (National Instruments) for collection and reduction of the data.

### Procedures

Testing and participant positioning replicated previously reported methods.[4,5,9] Individuals participated in 1 testing session and both ankles underwent 3 trials each of AP and I-E loading. To minimize variation, the arthrometer was positioned on all participants in a similar manner for all tests, and the same examiner (N.A.S.) performed all tests.

Each participant was positioned supine on a firm table with the knee in 10° to 20° of knee flexion and the foot extended over the edge of the table. A restraining strap attached to support bars under the table was secured around the distal lower leg approximately 1 cm above the malleoli and then tightened to prevent lower leg movement during testing. The examiner placed the bottom of the foot onto the footplate and secured the foot using heel and dorsal clamps. The heel clamp prevented the device from rotating on the calcaneus, and the dorsal clamp secured the foot to the footplate. The tibial reference pad then was positioned approximately 5 cm above the malleoli and secured to the lower leg with an elastic strap.

The ankle was positioned at zero AP load and zero I-E moment at a *neutral (0°) flexion angle*, which was defined as the measurement reference position.[2,4] The other degrees of freedom (internal-external, medial-lateral, and proximal-distal) also were maintained at their zero-load neutral position. Thus, the measurement reference position represented zero moment and force loads. This angle was measured from the plantar surface of the foot relative to the anterior tibia and determined by the 6-degrees-of-freedom electrogoniometer within the instrumented linkage. Anteroposterior loading, I-E torque, and the flexion angle were applied through the load handle in line with the footplate. Each trial involved reciprocal movements from the zero load to the maximum load. For the AP trial, the ankles were loaded to ±125 N with both anterior and posterior forces. Starting at the reference position, anterior loading was applied first; posterior loading, second. Total AP displacement of the ankle complex (millimeters) was recorded along with the loads. *Anterior motion* was defined as the displacement produced in response to the load changing from 0 to 125 N. *Posterior motion* was defined as the displacement produced in response to a load changing from 0 to −125 N. *Total AP displacement* was defined as the change produced in response to a load varying from −125 to 125 N. For I-E rotation, the ankles were loaded to ±4 Nm with both inversion and eversion torque. Starting at the neutral reference position, inversion loading was applied first; eversion loading, second. Rotation of the ankle complex was recorded along with the torque. *Inversion rotation* was defined as the angular displacement produced in response to a torque changing from 0 to 4 Nm. *Eversion rotation* was defined as the angular displacement produced in response to a torque changing from 0 to −4 Nm. *Total I-E rotation* was defined as the angular-displacement change produced in response to a torque varying from −4 to 4 Nm. By observing the computer monitor, the examiner visualized the applied load to obtain maximum AP displacement and I-E rotation.

Test order was assigned randomly between right and left ankles. After the ankle measurements were obtained, the device was removed, and the testing procedure was repeated on the contralateral ankle.

### Statistical Analysis

Anterior, posterior, and total AP displacement at 125 N and inversion, eversion, and total I-E rotation at 4 Nm were used as outcome measures. Descriptive data for all variables were expressed as the mean (±SD) score, median score, SE score, range of scores, and 95% confidence interval. The dominant and nondominant ankle-complex motion data from each of the 100 participants were first tested for normality. Normality of distribution was investigated using the Kolmogorov-Smirnov test with Lilliefors correction. If a finding of the Kolmogorov-Smirnov test was significant, normality of distribution was further investigated for that finding by examining the $z$ scores for skewness and kurtosis. If the $z$ scores for skewness and kurtosis of the variable were from +2.00 to −2.00, the finding was considered to be normally distributed. If the $z$ score for skewness of a finding was outside the +2.00 to −2.00 range, the finding was described as positively or negatively skewed. If the $z$ score for kurtosis of a finding was outside the +2.00 to −2.00 range, the finding was described as leptokurtic or platykurtic.

Limb-dominance data determined to be normally distributed were analyzed using the paired-samples $t$ test to identify any side-related difference between observations. Data determined not to be normally distributed were analyzed using the Wilcoxon test. Sex data determined to be normally distributed were analyzed using the independent-samples $t$ test to examine differences between men and women. Data determined not to be normally distributed were analyzed using the Mann-Whitney $U$ test. Effect size was determined using the Cohen d.[18] The $\alpha$ level was set a priori at .05. All statistical analyses were performed with SPSS software (version 17.0; SPSS Inc, Chicago, IL).

## RESULTS

### Limb Dominance

The findings of the Kolmogorov-Smirnov test were significant for total AP displacement of the dominant ankle ($D$ = 0.096, $P$ = .02), total AP displacement of the nondominant ankle ($D$ = 0.093, $P$ = .03), and inversion rotation of the dominant ankle ($D$ = 0.093, $P$ = .03). Examination of the $z$ scores for skewness and kurtosis showed normal distribution for total AP displacement of the dominant ankle (skewness = 0.33, SE = 0.24; kurtosis = −0.57, SE = 0.48) and total AP displacement of the nondominant ankle (skewness = 0.14, SE = 0.24; kurtosis = −0.40, SE = 0.48). The $z$ scores for inversion rotation of the dominant ankle (skewness = 0.68, SE = 0.24; kurtosis = 0.43, SE = 0.48) showed that this variable was positively skewed. Results indicated that all variables were normally distributed except for inversion rotation of the dominant ankle.

Bilateral comparisons revealed greater dominant than nondominant ankle-complex motion for total AP displacement (dominant = 19.23 ± 4.37 mm, nondominant = 16.26 ± 4.28 mm; $t_{99}$ = 6.43, $P < .01$, Cohen d = .68), posterior displacement (dominant = 9.64 ± 2.50 mm, nondominant = 7.30 ± 2.43 mm; $t_{99}$ = 6.78, $P < .01$, Cohen d = .95), and eversion rotation (dominant = 15.64° ± 4.92°, nondominant = 14.57° ± 4.83°; $t_{99}$ = 3.44, $P < .01$, Cohen d = .22). Greater inversion rotation was found for nondominant than for dominant ankle-complex motion (dominant = 22.16° ± 6.75°, nondominant = 23.85° ± 6.60°; $Z$ = −3.5, $P$ = .01, Cohen d = .25).

No differences were found between the dominant and nondominant ankles for anterior displacement (dominant = 9.58 ± 2.99 mm, nondominant = 8.96 ± 3.15 mm; $t_{99}$ = 1.9, $P$ = .06, Cohen d = .20) and total I-E rotation (dominant = 37.80° ± 10.44°, nondominant = 38.44° ± 10.26°; $t_{99}$ = −1.22, $P < .22$, Cohen d = .06). Small effect sizes were found for 4 of the 6 variables and were not considered clinically important; thus, the data from both ankles were pooled for all subsequent analyses.

### Sex Differences

Ankle-complex motion values in the male population of 100 ankles are shown in Table 1. The findings of the Kolmogorov-Smirnov test were significant for total I-E ($D$ = 0.097, $P$ = .02) and eversion ($D$ = 0.145, $P$ = .01) rotation. Examination of the $z$ scores showed normal distribution for total I-E rotation (skewness = 0.28, SE = 0.24; kurtosis = −0.78, SE = 0.48) and positive skewness for eversion rotation (skewness = 0.64, SE = 0.24; kurtosis = −0.30, SE = 0.48). Examination of frequency distributions for total AP displacement and total I-E rotation and their corresponding histograms graphically showed the distribution around the mean (Figures 1 and 2).

Ankle-complex motion values in the female population of 100 ankles are displayed in Table 2. The findings of the Kolmogorov-Smirnov test were significant for all the variables except posterior displacement. Examination of $z$ scores showed normal distribution for total AP displacement ($D$ = 0.113, $P$ = .01; skewness = 0.47, SE = 0.24; kurtosis = −0.36, SE = 0.48); positive skewness for anterior displacement ($D$ = 0.090, $P$ = .04; skewness = 0.75, SE = 0.24; kurtosis = 0.85, SE = 0.48), inversion ($D$ = 0.120, $P$ = .01; skewness = 0.67, SE = 0.24; kurtosis = −0.05, SE = 0.48), and total I-E rotation ($D$ = 0.121, $P$ = .01; skewness = 0.64, SE = 0.24; kurtosis = −0.29, SE = 0.48); and positive skewness and leptokurtosis for eversion rotation ($D$ = 0.109, $P$ = .01; skewness = 1.07, SE = 0.24; kurtosis = 1.47, SE = 0.48). Examination of frequency distributions for total AP displacement and total I-E rotation and their corresponding histograms graphically showed the distribution around the mean (Figures 3 and 4).

The women's ankles had greater motion than the men's ankles for all variables except posterior displacement (women's ankle motion = 8.82 ± 2.5 mm, men's ankle motion = 8.12 ± 2.9 mm; $t_{198}$ = −1.83, $P$ = .07). Mean total AP displacement of the women's ankles was 18.79 ± 4.1 mm and of the men's ankles was 16.70 ± 4.8 mm ($t_{198}$ = −3.306, $P < .01$). Anterior displacement was 9.95 ± 2.9 mm for the women's ankles and 8.59 ± 3.1 mm for the

Table 1. Descriptive Normative Data for Measurements of Ankle-Complex Motion in Men (N = 100 Ankles)

| Variable | Mean ± SD | SE | Median | Minimum | Maximum | Range | 95% Confidence Interval |
|---|---|---|---|---|---|---|---|
| Total anteroposterior displacement, mm | 16.70 ± 4.76 | 0.47 | 16.18 | 7.61 | 29.53 | 21.92 | 17.65, 15.76 |
| Anterior displacement, mm | 8.59 ± 3.10 | 0.31 | 8.05 | 1.71 | 15.26 | 13.55 | 9.20, 7.97 |
| Posterior displacement, mm | 8.12 ± 2.92 | 0.29 | 7.85 | 0.42 | 16.71 | 16.29 | 8.70, 7.54 |
| Total inversion-eversion rotation, ° | 34.13 ± 10.06 | 1.00 | 32.06 | 14.54 | 56.50 | 41.96 | 36.13, 32.14 |
| Inversion rotation, ° | 20.52 ± 6.29 | 0.62 | 19.88 | 8.32 | 38.14 | 29.82 | 21.77, 19.27 |
| Eversion rotation, ° | 13.61 ± 4.74 | 0.47 | 12.01 | 5.49 | 27.30 | 21.81 | 14.55, 12.67 |

men's ankles ($U$ = 3708.5, $P$ = .002). The mean total I-E rotation of the women's ankles was 42.10° ± 9.0° and of the men's ankles was 34.13° ± 10.1° ($U$ = 2807, $P < .001$). Inversion rotation was 25.49° ± 6.2° for the women's ankles and 20.52° ± 6.3° for the men's ankles ($U$ = 2800.5, $P < .001$). Eversion rotation was 16.60° ± 4.6° for the women's ankles and 13.61° ± 4.7° for the men's ankles ($U$ = 3117, $P < .001$).

## DISCUSSION

Instrumented ankle arthrometry was introduced in 1999 as an assessment tool to provide objective and quantifiable assessment of ankle-complex motion.[4] Other authors[3,5,6,8–16] have reported the advantages of this procedure for detecting ankle ligamentous laxity after injury. We performed this study to characterize the normal magnitude of physiologic ankle-complex motion in a population of uninjured ankles measured with the Hollis Ankle Arthrometer.

### Limb Dominance

From a clinical perspective, assessment of ankle-complex motion should be made bilaterally and, when possible, against established normative data.[19] This is especially important when testing an individual's functional status after ligamentous and capsular injury. Thus, knowing if ankle-complex motion between ankles in the same individual differs is imperative for accurate diagnosis. To date, few investigators have quantified differences in the uninjured ankle complex for right and left or dominant and nondominant motion,[4,20,21] primarily because a reliable and repeatable method for quantifying ankle-complex motion has been unavailable.[22–24] Our data are far more comprehensive than the data that normally are used to evaluate ankle-complex motion, except when researchers use a device similar to the Hollis Ankle Arthrometer as an evaluation tool.

Examination of the effect sizes for the variables quantifying ankle-complex motion confirmed that within-subjects differences between the dominant and nondominant ankles were, on average, small and, therefore, not clinically important.[18,25,26] These findings of symmetry were consistent with previous reports of the mechanical laxity characteristics of the ankle complex between legs.[4,20,21] Based on data obtained using 3-dimensional kinematics, Stefanyshyn and Engsberg[20] determined that ranges of motion for inversion, eversion, and total I-E were not different between the right and left legs in participants with no history of ankle injury. Siegler et al[21] noted no differences for inversion, eversion, or total I-E rotation comparisons of left and right ankles. They reported the average range of motion from paired-ankles data as 21.7° ± 3.8° for eversion, 20.0° ± 4.8° for inversion, and 42.0° ± 4.2° for total I-E rotation. In uninjured ankles, Kovaleski et al[4] found no differences between dominant and nondominant ankles for total I-E rotation (dominant =

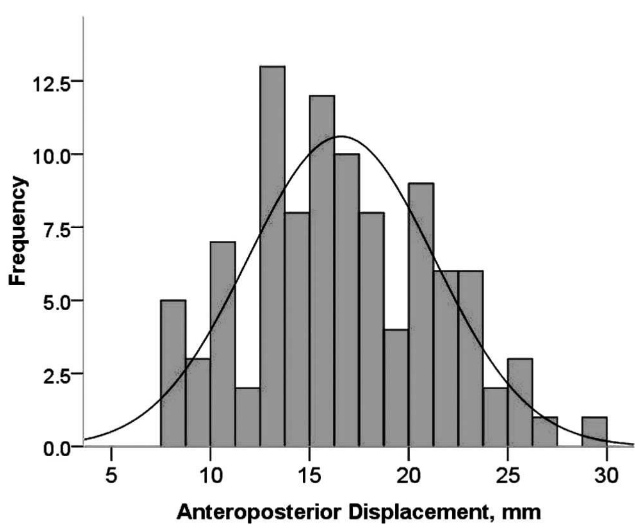


Figure 1. Range of frequency distribution for anteroposterior displacement of the men's ankles (N = 100 ankles). The mean was 16.70 ± 4.8 mm.

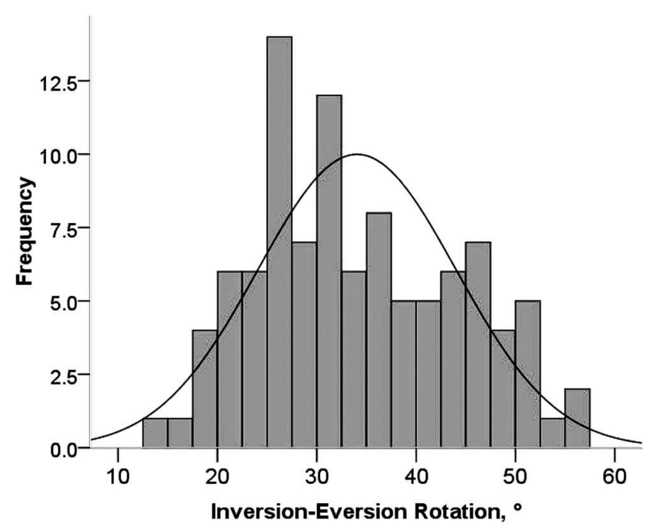


Figure 2. Range of frequency distribution for inversion-eversion rotation of the men's ankles (N = 100 ankles). The mean was 34.13° ± 10.1°.

**Table 2. Descriptive Normative Data for Measurements of Ankle-Complex Motion in Women (N = 100 Ankles)**

| Variable | Mean ± SD | SE | Median | Minimum | Maximum | Range | 95% Confidence Interval |
|---|---|---|---|---|---|---|---|
| Total anteroposterior displacement, mm | 18.79 ± 4.12 | 0.41 | 18.58 | 11.01 | 29.96 | 18.95 | 19.60, 17.97 |
| Anterior displacement, mm | 9.95 ± 2.91 | 0.29 | 9.53 | 4.83 | 20.66 | 15.83 | 10.53, 9.38 |
| Posterior displacement, mm | 8.82 ± 2.48 | 0.24 | 8.39 | 3.05 | 13.86 | 10.81 | 9.31, 8.33 |
| Total inversion-eversion rotation, ° | 42.10 ± 9.00 | 0.90 | 39.90 | 26.19 | 62.90 | 36.71 | 43.89, 40.32 |
| Inversion rotation, ° | 25.49 ± 6.21 | 0.62 | 24.39 | 13.13 | 41.88 | 28.75 | 26.72, 24.25 |
| Eversion rotation, ° | 16.60 ± 4.59 | 0.45 | 16.09 | 9.60 | 32.71 | 23.11 | 17.51, 15.69 |

46.19° ± 12.2°, nondominant = 47.38° ± 14.3°) and total AP displacement (dominant = 18.47 ± 5.1 mm, nondominant = 17.51 ± 5.4 mm). This study is the only investigation that we found in which researchers examined the effect of ankle dominance on ankle-complex motion using the Hollis Ankle Arthrometer. Limb-dominance comparisons of ankle-complex motion between our study and other studies in which the authors reported using the Hollis Ankle Arthrometer were confounded because limb dominance was not identified in those studies.[5,8–10,13–16] Of the other studies in which differences between left and right ankles were examined, injured ankles were included in the data analysis.[11,12]

## Sex Differences

Joint hypermobility describes the often asymptomatic increased range of joint movement and is about 3 times more common in females than males.[27] Beighton et al[28] and others[29,30] reported that women possess higher generalized joint hypermobility scores than men. This finding also corresponds with data presented in studies of joint-specific laxity that revealed women have greater knee and ankle laxity values than men.[15,31,32] In addition, data consistently have shown differences in ankle motion and in ankle-injury patterns between men and women.[31,33–35] Results from a recent study based on stress radiography measurements showed a greater mean inversion talar tilt for women's ankles (3.2° ± 3.3°) than men's ankles (1.1° ± 1.5°).[33] In a prospective study of 4940 female and 6840 male collegiate basketball players, female players had a 25% greater risk of sustaining a grade I ankle sprain.[35] These data indicated that female athletes might have a higher risk of sustaining an acute ankle sprain when participating in the same sport as male athletes. Knowing a sex bias can exist for the normal distribution of ankle-complex motion is imperative for accurate bilateral comparison between ankles after injury.

Our main finding regarding the effects of sex on ankle-complex motion was that women's ankles were more lax than men's ankles. The mean range of motion was 7.97° greater for total I-E rotation (42.10° ± 9.00° versus 34.13° ± 10.06°), 4.97° greater for inversion rotation (25.49° ± 6.21° versus 20.52° ± 6.29°), and 2.99° greater for eversion rotation (16.60° ± 4.59° versus 13.61° ± 4.74°) for the women's than the men's ankles. For AP displacement, mean total AP displacement was 2.09 mm (18.79 ± 4.12 versus 16.70 ± 4.76 mm), anterior displacement was 1.36 mm (9.95 ± 2.91 versus 8.59 ± 3.10 mm), and posterior displacement was 0.7 mm (8.82 ± 2.48 versus 8.12 ± 2.92 mm) greater in the women's than in the men's ankles. The relatively large SDs indicated sizable variations in both men's and women's ankle-complex motion, which implies that a relatively large range of possible motion exists within the uninjured ankle.[4,5,14] Researchers using the Hollis Ankle Arthrometer have shown low standard error of measurement.[3–5] This is important because high precision of measurement using the Hollis Ankle Arthrom-

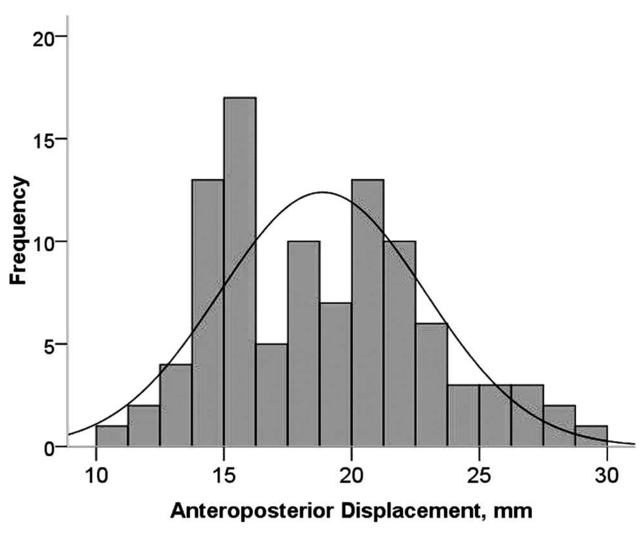


**Figure 3. Range of frequency distribution for anteroposterior displacement of the women's ankles (N = 100 ankles). The mean was 18.79 ± 4.1 mm.**

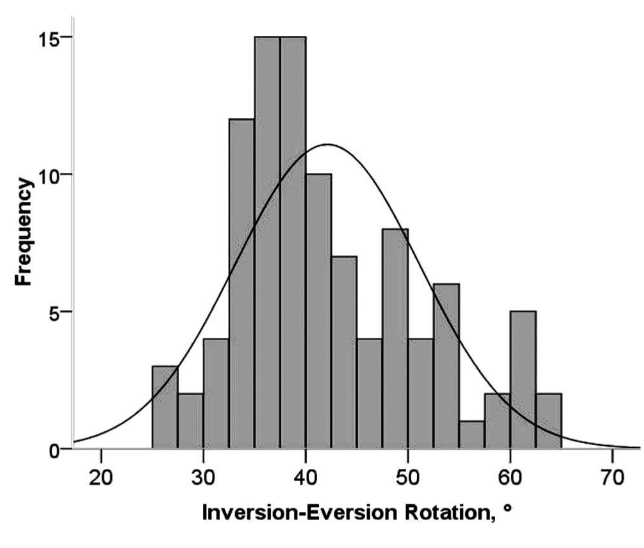


**Figure 4. Range of frequency distribution for inversion-eversion rotation of the women's ankles (N = 100 ankles). The mean was 42.1° ± 9.0°.**

**Table 3. Reference Ranges (Number of Ankles in Each Range) Illustrating the Potential Association Among Ankle-Complex Motions in Men**

| Type of Laxity | Excessive Hypomobility, >−2 SDs | Hypomobility, −1 SD, −2 SDs | Normal Mobility, −1 SD, +1 SD | Hypermobility, +1 SD, +2 SDs | Excessive Hypermobility, >+2 SDs |
|---|---|---|---|---|---|
| Total anteroposterior displacement, mm | ≤7.17 (0) | 7.18, 11.93 (15) | 11.94, 21.46 (67) | 21.47, 26.22 (16) | ≥26.23 (2) |
| Anterior displacement, mm | ≤2.38 (2) | 2.39, 5.48 (12) | 5.49, 11.69 (62) | 11.70, 14.79 (20) | ≥14.80 (2) |
| Posterior displacement, mm | ≤2.27 (4) | 2.28, 5.19 (7) | 5.20, 11.04 (75) | 11.05, 13.96 (9) | ≥13.97 (5) |
| Total inversion-eversion rotation, ° | ≤14.00 (0) | 14.01, 24.06 (16) | 24.07, 44.19 (64) | 44.20, 54.25 (18) | ≥54.26 (2) |
| Inversion rotation, ° | ≤7.93 (0) | 7.94, 14.22 (15) | 14.23, 26.81 (68) | 26.82, 33.10 (13) | ≥33.11 (4) |
| Eversion rotation, ° | ≤4.12 (0) | 4.13, 8.86 (18) | 8.87, 18.35 (64) | 18.36, 23.09 (14) | ≥23.10 (4) |

eter indicates that any measurement inconsistency occurs in an acceptably small range of values.

Authors of only 2 published studies have reported comparisons of ankle-complex motion between men's and women's ankles using the Hollis Ankle Arthrometer. Kovaleski et al[14] examined the effects of sex and competitive status between collegiate athletes and nonathletes on total I-E range of motion and reported that ankle-complex rotational range of motion was greater in women than men and that it did not differ between athletes and nonathletes. They reported an average I-E rotation for the male (42.1° ± 12.8°) and female (48.3° ± 10.6°) participants' ankles that was greater than the values reported in our study (men's I-E rotation = 34.13° ± 10.1°, women's I-E rotation = 42.10° ± 9.0°). In another study, Pearsall et al[15] examined the relationship between instrumented measurements of ankle and knee ligamentous laxity and generalized joint laxity. Although statistical comparisons of ankle-complex motion were not performed, the authors reported a greater average I-E rotation in the female athletes' ankles (46.6° ± 11.2°) than in the male athletes' ankles (38.11° ± 10.0°). These values were only slightly higher than the I-E rotation values observed in our study. For AP displacement, Pearsall et al[15] reported a mean difference of only 0.61 mm between the 29 men (18.5 ± 5.3 mm) and 28 women (17.9 ± 4.8 mm) whom they studied. In our study, a slightly greater mean difference of 2.09 mm for AP displacement was observed between the men's and women's ankles (Table 2).

## Distribution of the Data

Seven of the 12 variables quantifying ankle-complex motion were normally distributed. The remaining variables were positively skewed, with 4 of these variables (anterior displacement, total I-E rotation, inversion rotation, and eversion rotation) observed in women. For each of these variables, the means were slightly greater than the medians (Table 2). The largest difference was observed for total I-E rotation in women, for whom a mean of 42.10° and a median value of 39.90° were observed.

The bell-shaped distribution for each variable of ankle-complex motion can be described using the sample mean and SD and, because of the sample size used, these data can become good estimates of the population mean and SD for the ankles of young men and women. Therefore, these data form the basis of norm-referenced clinical tests, with the number of SDs greater or less than the mean used for classification into categories according to ankle-complex motion.[25,36]

Reference ranges for ankle complex motion were defined using the cut points used previously for similar studies, namely, normal (values lying in the range of mean ± 1 SD), hypomobility (−1 to −2 SDs from the mean), excessive hypomobility (>−2 SDs from the mean), hypermobility (+1 SD to +2 SDs from the mean), and excessive hypermobility (>+2 SDs from the mean).[25,36,37] Using this schema, the presence and severity of ankle hypomobility and hypermobility in individuals and in patient populations can be determined (Table 3 for men and Table 4 for women). Most values fell within ±2 SDs of the mean. The tendency for outliers to be greater than +2 SDs from the mean caused the positive skewness observed for these variables. In addition, outlier scores were more frequent and larger in the women's ankles. For women's total I-E rotation, values for 7 ankles were greater than +2 SDs, whereas no values were greater than −2 SDs. For men's total I-E rotation, values for only 2 ankles were greater than +2 SDs. Total I-E rotation for the women's ankles ranged from 33.10° to 51.10°, whereas total I-E rotation ranged from 24.07° to 44.19° for the men's ankles.

## CONCLUSIONS

Our findings illustrated that normal between-subjects ankle motion existed in a large range. Understanding

**Table 4. Reference Ranges (Number of Ankles in Each Range) Illustrating the Potential Association Among Ankle-Complex Motions in Women**

| Type of Laxity | Excessive Hypomobility, >−2 SDs | Hypomobility, −1 SD, −2 SDs | Normal Mobility, −1 SD, +1 SD | Hypermobility, +1 SD, +2 SDs | Excessive Hypermobility, >+2 SDs |
|---|---|---|---|---|---|
| Total anteroposterior displacement, mm | ≤10.54 (0) | 10.55, 14.66 (16) | 14.67, 22.91 (69) | 22.92, 27.03 (11) | ≥27.04 (4) |
| Anterior displacement, mm | ≤4.12 (0) | 4.13, 7.03 (18) | 7.04, 12.86 (66) | 12.87, 15.77 (14) | ≥15.78 (2) |
| Posterior displacement, mm | ≤3.85 (3) | 3.86, 6.33 (09) | 6.34, 11.30 (69) | 11.31, 13.78 (18) | ≥13.79 (1) |
| Total inversion-eversion rotation, ° | ≤24.09 (0) | 24.10, 33.09 (12) | 33.10, 51.10 (71) | 51.11, 60.10 (10) | ≥60.11 (7) |
| Inversion rotation, ° | ≤13.06 (0) | 13.07, 19.27 (14) | 19.28, 31.70 (70) | 31.71, 37.91 (13) | ≥37.92 (3) |
| Eversion rotation, ° | ≤7.41 (0) | 7.42, 12.00 (14) | 12.01, 21.19 (69) | 21.20, 25.78 (14) | ≥25.79 (3) |

normalcy is important for determining excessive motion (laxity) after injury, the need for treatment interventions, and the efficacy of treatment. Important distinctions in ankle-complex motion were noted by sex. Because ankle-complex motion was, on average, greater in women than in men, the range of motion in the normal reference range, along with hypermobility and excessive hypermobility, needs to be considered and set at a higher reference value in women than in men when clinicians contemplate intervention. In the future, researchers should focus on identifying differences in ankle-complex motion among athletes and individuals of different ages. Researchers also should study whether ankle-complex motion greater or less than the normal reference range affects incidence of ankle injury so that appropriate injury-prevention initiatives can be developed.

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# Chronic Ankle Instability: Evolution of the Model

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***Context:*** The Hertel model of chronic ankle instability (CAI) is commonly used in research but may not be sufficiently comprehensive. Mechanical instability and functional instability are considered part of a continuum, and recurrent sprain occurs when both conditions are present. A modification of the Hertel model is proposed whereby these 3 components can exist independently or in combination.

***Objective:*** To examine the fit of data from people with CAI to 2 CAI models and to explore whether the different subgroups display impairments when compared with a control group.

***Design:*** Cross-sectional study.

***Patients or Other Participants:*** Community-dwelling adults and adolescent dancers were recruited: 137 ankles with ankle sprain for objective 1 and 81 with CAI and 43 controls for objective 2.

***Intervention(s):*** Two balance tasks and time to recover from an inversion perturbation were assessed to determine if the subgroups demonstrated impairments when compared with a control group (objective 2).

***Main Outcome Measure(s):*** For objective 1 (fit to the 2 models), outcomes were Cumberland Ankle Instability Tool score, anterior drawer test results, and number of sprains. For objective 2, outcomes were 2 balance tasks (number of foot lifts in 30 seconds, ability to balance on the ball of the foot) and time to recover from an inversion perturbation. The Cohen d was calculated to compare each subgroup with the control group.

***Results:*** A total of 56.5% of ankles ($n = 61$) fit the Hertel model, whereas all ankles ($n = 108$) fit the proposed model. In the proposed model, 42.6% of ankles were classified as perceived instability, 30.5% as recurrent sprain and perceived instability, and 26.9% as among the remaining groups. All CAI subgroups performed more poorly on the balance and inversion-perturbation tasks than the control group. Subgroups with perceived instability had greater impairment in single-leg stance, whereas participants with recurrent sprain performed more poorly than the other subgroups when balancing on the ball of the foot. Only individuals with hypomobility appeared unimpaired when recovering from an inversion perturbation.

***Conclusions:*** The new model of CAI is supported by the available data. Perceived instability alone and in combination characterized the majority of participants. Several impairments distinguished the sprain groups from the control group.

***Key Words:*** ankle injuries, joint instability, postural balance, recurrent ankle sprains

**Key Points**

- The proposed new model of chronic ankle instability is supported by data from previous studies and the current study. More subgroups are identified than in previous models, with perceived instability as a common link.
- On balance tests, all groups with chronic ankle instability performed more poorly than control groups.
- The model will allow the development of specific injury-rehabilitation and injury-prevention programs for subgroups of chronic ankle instability.

Ankle sprains are very common not only in the sporting population[1] but also in the general community.[2] Although the acute symptoms of ankle sprain resolve quickly, many people report persisting problems, such as pain and instability.[3] Chronic ankle instability (CAI) is one of the most common of these residual problems[3] and has been defined as "repetitive bouts of lateral ankle instability resulting in numerous ankle sprains."[4] Despite the high prevalence of CAI, it remains a phenomenon that is poorly understood by researchers and clinicians alike. This has resulted in inconsistencies in terminology, definitions, and in hypotheses about impairments,[4] relationships among the impairments,[5] and the relative contributions of the impairments to activity limitations and participation restrictions.

The World Health Organization has classified the effects of disease in terms of *impairments*, which refer to problems in body structure or function; *activity limitations*, which refer to difficulties in execution of activities; and *participation restrictions*, which refer to changes in life situations, often involving a physical component (International Classification of Functioning, Disability, and Health).[6] Impairments associated with CAI include increased ligamentous laxity and proprioceptive deficits. Activity limitations affect the execution of activities such as walking or jumping.[7] Participation restrictions as a consequence of CAI can include cessation of sport or occupational involvement.

Inconsistencies in CAI research may be explained, in part, by the common assumption that CAI is a homogeneous condition. That is, it is often assumed that all cases of CAI arise from the same injury and develop the same impairments, leading to a consistent relationship between impairments and activity limitations. This assumption likely explains the conflicting results from investigations of CAI. If CAI is a heterogeneous condition that includes several homogeneous subgroups, conflicting reports of impairments, activity limitations, and participation restrictions may reflect researchers' recruitment of either an idiosyncratically determined subgroup or a heterogeneous population, thereby "washing out" significant findings.

The ability to define subgroups that constitute CAI would allow focused investigations of each of these homogeneous subgroups. Such a classification would aid the exploration of relationships among subgroups, including whether each subgroup is characterized by different impairments, activity limitations, and participation restrictions and, consequently, facilitate the development of targeted treatment and prevention strategies.

## HISTORICAL BACKGROUND OF THE CONCEPT OF CAI

Historically, several terms have been used interchangeably to describe the phenomenon of ankle instability, including *chronic ankle instability*,[8] *chronic lateral ankle instability*,[9] *ankle instability*,[10] *residual ankle instability,*[11] *chronic instability,*[12] *recurrent instability,*[13] *recurrent lateral ankle instability,*[14] and *chronic ankle sprain*.[15] Although there is no consensus that these terms represent the same phenomenon, we consistently use the term *chronic ankle instability* (CAI) in this retrospective study.

The most commonly cited characteristics of CAI include giving way of the ankle,[9,16–18] mechanical instability,[9,18–20] pain and swelling,[14,17,20,21] loss of strength,[22] recurrent sprain,[5,20,23–25] and functional instability.[9,18,26] Residual problems can persist for decades,[27] with up to 72% of people unable to return to their previous level of activity.[28] Some residual problems, such as fear of the ankle giving way, have been reported to continue to worsen over time rather than improve.[29] Additionally, the likely development of impairment and activity limitation is independent of the severity of the initial injury[30–34] and is not confined to the injured limb; problems have been reported in the contralateral ankle of 85% of people who develop CAI after unilateral sprain.[28] Reported participation restrictions include decreasing the level of exercise,[28] change in type of sport,[35] and withdrawing from occupational activity.[29]

The earliest investigators of CAI described 2 subgroups: those with patient-reported ankle symptoms and those with abnormal physical findings.[36] Freeman[37] subsequently termed these ankle symptoms *functional instability*. He defined functional instability as the tendency for the foot to give way. Thus, 2 main subgroups of CAI became widely accepted: those with mechanical instability and those with functional ankle instability.

Although the definition of mechanical instability is universally accepted as pathologic ligamentous laxity about the ankle-joint complex,[4,12,18,19] no universally approved definition of functional ankle instability exists.[38] Evans et al[31] described functional instability as a subjective complaint of weakness; this description was expanded by Lentell et al[16] to include pain and the perception that the ankle felt less functional than the other ankle and less functional than before the injury. Tropp et al[39] distinguished functional instability from mechanical instability by defining it as joint motion that did not necessarily exceed normal physiologic limits but that was beyond voluntary control. Other proposed characteristics of functional ankle instability have included perceived or actual giving way of the ankle (or both)[10,16,40] and other characteristics previously associated with CAI in general: pain and swelling[30] and recurrent sprain.[41,42] That is, various definitions of functional ankle instability have been used to determine eligibility criteria when recruiting participants to studies. Such differences in inclusion criteria may explain the inconsistent findings from CAI research to date.

The relationship between mechanical instability and functional instability has also been widely debated and variously described as "little or none,"[9,20] "not constant,"[43] and "commonly occurring."[44] The proposed temporal relationship between mechanical and functional instability also varies, with functional ankle instability inferred as either a direct consequence of mechanical instability[34] or, conversely, a cause of mechanical instability.[45] Recurrent sprain is further proposed to be an independent consequence of mechanical instability,[46] functional instability,[47] or both.[45] Thus, little consensus exists in the literature as to the relationship among these variables.

Hertel[4] proposed a model involving mechanical and functional instability that is widely accepted. In this model, mechanical and functional instability are not mutually exclusive but part of a continuum, and recurrent sprain occurs when both conditions are present. Mechanical instability is thought to result from various anatomic changes that may exist in isolation or in combination. These changes are proposed to lead to insufficiencies that predispose the person to further episodes of instability. Functional instability is proposed to result from functional insufficiencies such as impaired proprioceptive and neuromuscular control.[4] When mechanical and functional insufficiencies are present, recurrent sprain results. However, anecdotally, participants have reported residual feelings of instability and ankle laxity after ankle sprain but have not reinjured their ankles. This has led to a potential evolution of the Hertel model, separating recurrent sprain from the presence of both instabilities. Thus, our first objective was to propose a refinement of the CAI model proposed by Hertel. The new model expands the number of subgroups from 3 to at least 7 and examines the fit of available ankle data to both models.

We hypothesized, based on preliminary evidence, that impairments may vary among the subgroups of the proposed model.[34,39,40,45] For example, previous researchers[34,39,48] demonstrated that postural stability was impaired in participants with functional instability, whether or not mechanical instability was present. In contrast, peroneal reaction times after an inversion perturbation were longer in participants with functional instability without mechanical instability than in those with mechanical instability alone.[45] Thus, depending on the impairment, participants with mechanical and functional instability may perform differently than those with only functional instability. Further exploration of all subgroups in the proposed model may reveal unique sets of impairments characterizing that subgroup.

If homogeneous subgroups exist within the broad category of those with CAI, then the presence or absence of impairments and the relationships among impairments, activity limitations, and participant restrictions can be better clarified. Our second objective, therefore, was to explore if impairments within the subgroups differ from those within a control group or from each other.

## METHODS

### Objective 1: Fit of Data to the Models

**Proposed Subgroups Within CAI.** The model that we propose is an evolution of the Hertel original model. Hertel[4] originally described CAI as consisting of 2 subgroups, classified according to the presence of either mechanical instability or functional instability; when these 2 impairments coexist, a third subgroup, recurrent sprain, arises. Unlike the Hertel model, however, our new model proposes that all 3 subgroups, including recurrent sprain, can be present either independently or as comorbid entities, resulting in 7 subgroups (Figure 1). We developed the new model while analyzing data from 2 recent studies[49,50] to enable classification of all ankles with CAI, because not all ankles could be classified according to the Hertel model. In particular, a number of participants had both mechanical and functional instability but did not suffer recurrent sprains, and, conversely, some participants suffered recurrent sprains but had neither mechanical nor functional instability.

Because *functional instability* is now used with widely different meanings, we further propose that the term *functional instability* be replaced by *perceived instability*. The single characteristic of functional instability on which there is consensus dating back to the original observations of Freeman[37] is that the patient perceives the ankle to be unstable, whether or not this perception is associated with physical signs. Recently, questionnaires have been developed to quantify functional instability,[51–54] and each of these has consistently relied on the perception of instability as the basis for the instrument. Use of the term *perceived instability* would clarify the difference between the impairments involved in CAI and any functional or activity limitations that may result or coexist.

**Data Extraction.** To examine the fit of available ankle data to both models, we used data from 2 of our recent studies.[49,50] In one study,[50] we assessed 115 adolescent dancers (age = 14.2 ± 1.8 years) at baseline, and followed them for 13 months or until they sustained an inversion ankle sprain. In the other study,[49] we tested 41 adults (age = 23.1 ± 6.7 years) with functional ankle instability for various impairments and compared them with 20 healthy control participants (age = 24.5 ± 9.9 years). *Functional ankle instability* was defined as the perception that the ankle was chronically weaker, more painful, or less functional than the other ankle or than before the first sprain.

The following criteria were used for fitting data to the models. Functional or perceived instability was defined as a score of ≤27 on the Cumberland Ankle Instability Tool (CAIT).[51] The CAIT is a valid and reliable measure of functional ankle instability.[51] To assess mechanical instability at the ankle, the modified anterior drawer test (in which the tibia is moved backward on the talus) was performed. On a 4-point scale, hypomobility was defined as *0*, normal range as *1* or *2*, and severely lax and mechanically unstable as *3*. Although using a manual test for ligament laxity has known limitations, the same examiner tested all ankles and was blind to ankle status. Intrarater reliability for this method is excellent.[55] For the purposes of this paper and in the absence of an agreed-upon definition, we defined *recurrent sprain* as a history of 3 or more sprains to the same ankle.

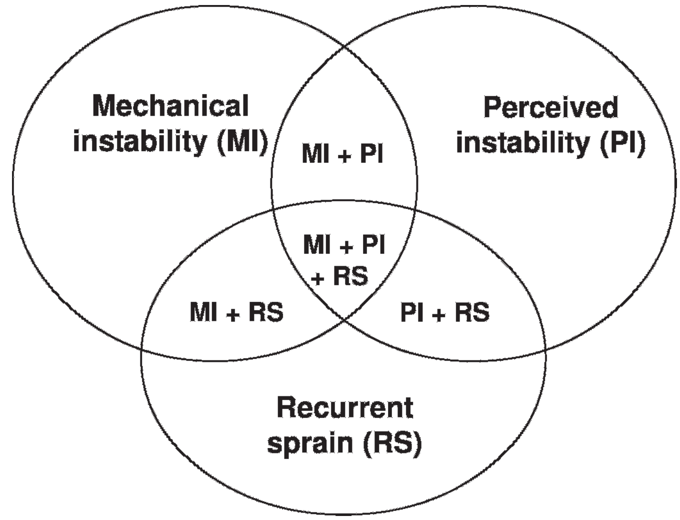


**Figure 1. Chronic ankle instability model showing the 7 proposed subgroups.**

In the 2 studies combined, a total of 137 ankles had sustained sprains. Excluded from further analysis were 29 ankles: 15 were considered recovered because they had a normal anterior drawer test, CAIT score ≥28, and no resprain; 14 displayed hypomobility on the anterior drawer test. Thus, 108 ankles were included in the first analysis (Figure 2).

### Objective 2: Types of Impairments Associated With Subgroups and Compared With Controls

To explore whether impaired performance in selected physiologic and functional tests was associated with different subgroups and was not impaired in control participants, we compared the findings on these tests from our same 2 studies.[49,50] We included those tests common to the 2 studies: 2 measures of balance and 1 measure of motor control. One measure of balance was the number of foot lifts in 30 seconds while balanced on 1 leg with the eyes closed.[49] For this test, participants stood in a standardized position on 1 leg. They looked straight ahead, and their arms were relaxed by their sides. The non–weight-bearing leg was bent so that the foot touched the calf of the stance leg. The number of times any part of the stance foot lifted off the floor was counted in a 30-second period. Foot lifts included, for example, lifting of the first metatarsophalangeal or toe joint or shifting of the foot across the floor. The second test was the ability to balance on the ball of the foot (demipointe) for 5 seconds.[49] From a standardized position, the heel was lifted from the floor and the participant balanced without moving. Motor control was assessed as the time to recover from an inversion perturbation. Oscillation in the mediolateral direction was measured using a 3-dimensional tracking device (FASTRAK; Polhemus, Colchester, VT) while standing on 1 leg with the foot flat. A 15° inversion perturbation was applied, and the time until stabilization of the mediolateral oscillation was determined. Further information on these methods is published elsewhere.[49,50]

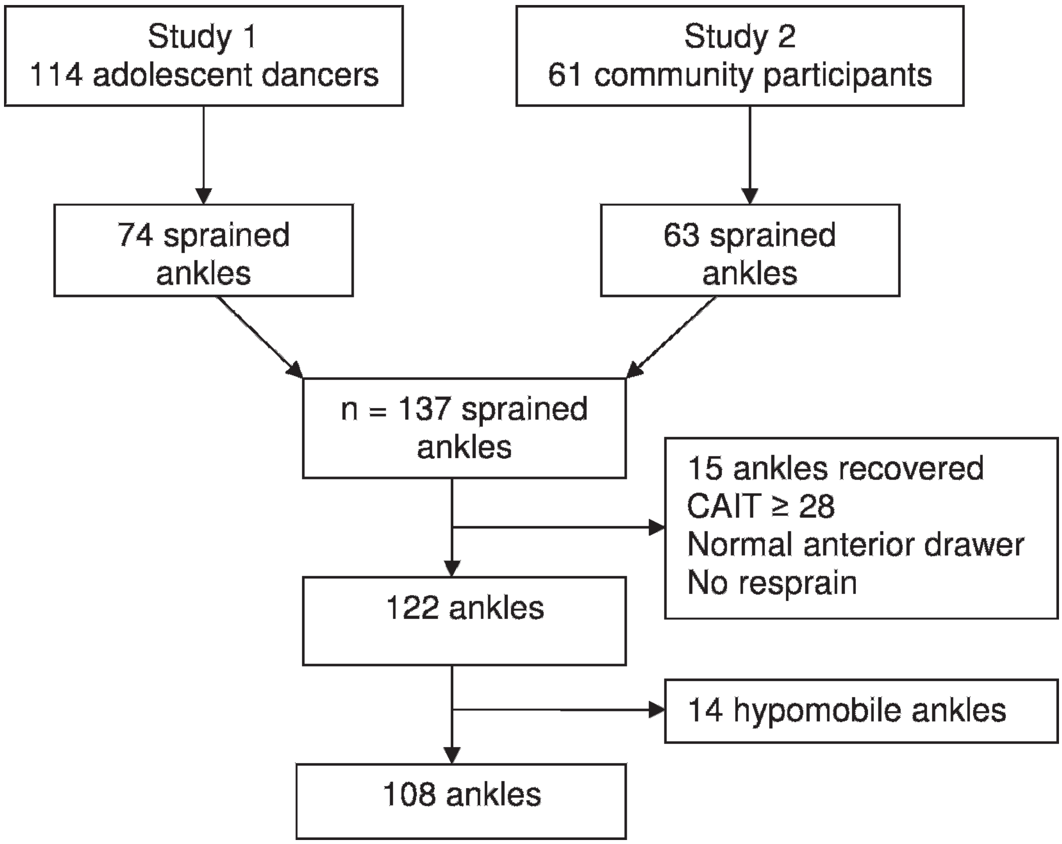


**Figure 2. Flow chart of ankle selection for objective 1: fit of ankles to the models. Abbreviation: CAIT, Cumberland Ankle Instability Tool.**

To analyze relationships between test performance and group, data from only 1 ankle of each participant were included. Therefore, for participants with bilateral instability, we analyzed data from the more severely affected ankle, that is, the ankle that could be classified in several subgroups. In cases of bilateral instability with the same classification for both ankles, the ankle with the lower CAIT score was used.

Data from healthy, uninjured participants (external controls) from these same 2 studies were included to enable further comparison. To be included as an external control, participants were required to have no history of ankle sprain, a CAIT score ≥28, and a normal anterior drawer test in each ankle. The test ankle for external controls was randomly selected.

Of the original 175 participants, 52 were excluded, either because they had fully recovered from an ankle sprain (n = 15) or because they were healthy uninjured participants who did not meet the inclusion criteria (n = 37). This resulted in 81 participants with CAI and 42 external controls. Of the participants with CAI, 45 had unilateral CAI and 36 had bilateral CAI. The test ankle for 15 of the participants with bilateral instability was selected on the basis of CAIT score because of similar classification for both ankles.

To explore if hypomobility is associated with different impairments, we included the data from participants with that characteristic. Of the 81 participants, 10 were classified as hypomobile. For participants with bilateral hypomobility, the same criteria used above were used to determine which ankle to include.

## Statistical Analysis

Because the study was a retrospective exploration, we performed no statistical analysis for significance. Refinement of the Hertel model (objective 1) was determined by calculating the numbers and percentage fit of the ankles into each of the subgroups. To assess whether impairments within the different subgroups differed from a control group or from each other (objective 2), we described the measures of balance, which included the average number of foot lifts (mean ± SE) and the number of people in each subgroup and among the external controls who failed to balance on demipointe. In addition, for each subgroup and the external controls, we described the measure of motor control, which was the time to recover from an inversion perturbation (mean ± SE). A number of participants failed to return to their preperturbation performance in the test time, so they were assigned a time of 4.5 seconds, which was 0.5 seconds longer than the longest recovery time of those who completed the task. This method of analysis has been used previously.[56] Ideally, survival analysis would be used for such data, but it is inappropriate here because of the retrospective nature of this analysis.

To assist in comparing the external-control participants with the various subgroups and to give some indication of impairment severity, the Cohen d, using the pooled SD of the external controls and the subgroup of interest, was calculated. In addition, plots were drawn of the mean and 95% confidence intervals for the number of foot lifts in 30 seconds and the time for each group to recover from a perturbation. If confidence intervals overlap by a quarter of the average length of the intervals and the group sizes

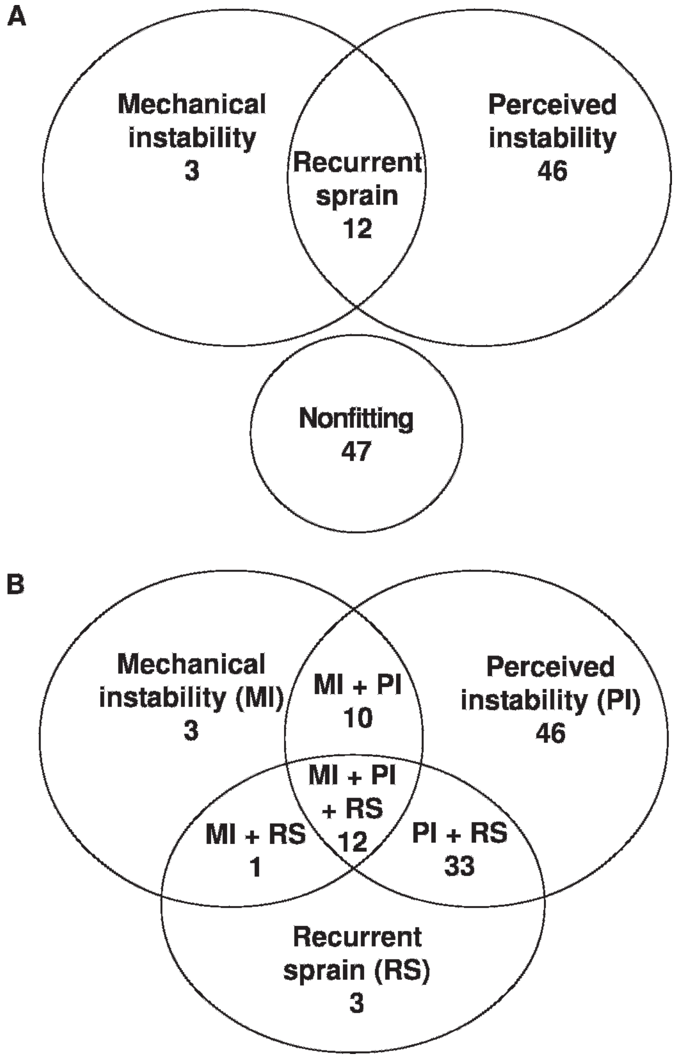


**Figure 3. Fit of the ankle data to the Hertel[4] model (A) and the new model (B). A total of 47 ankles did not fit the Hertel model.**

are greater than 10, then this is an indication that the *P* value would be close to .05.[57]

## RESULTS

### Objective 1: Fit of Data to the Models

In the first analysis (n = 108 ankles), 61 ankles (56.5%) fit the Hertel model and 47 ankles did not (Figure 3). Data from all 108 ankles fit the new proposed model with high fidelity for each subgroup. The percentage fit for the proposed subgroups was perceived instability, 42.6%; perceived instability and recurrent sprain, 30.5%; perceived and mechanical instability and recurrent sprain, 11.1%; mechanical and perceived instability, 9.3%; mechanical instability, 2.8%; recurrent sprain, 2.8%; and mechanical instability and recurrent sprain, 0.9%.

### Objective 2: Level of Impairments Within Different Subgroups Compared With Control Group

The second analysis of 81 participants suggested that all subgroups were impaired on at least 1 measure compared with external controls: that is, they experienced more failures in the demipointe perturbation test, had more foot lifts in the single-leg–stance test, and took longer to recover from a perturbation (Table; Figures 4 and 5). However, impairment severity varied. We could not further explore 3 subgroups (mechanical instability, recurrent sprain, and mechanical instability plus recurrent sprain) because each cell contained too few participants.

Performance in the foot-lifts test of balance was impaired in all subgroups compared with external controls, although the hypomobility group appeared to be less impaired. In contrast, performance in the balancing-on-demipointe test indicated that participants with recurrent sprain in combination with mechanical or perceived instability (or both) performed more poorly than participants with perceived instability with or without mechanical instability and the hypomobility group. The level of impaired performance was similar for the test of recovery from a perturbation among the tested subgroups except for the hypomobility group, which appeared to be unimpaired compared with the external controls.

## DISCUSSION

### Fit of the New Model

The good data fit from our 2 recent studies to the new model gives preliminary support to the proposed 7 subgroups of CAI. The original concept of subgroups based on mechanical instability, perceived instability, and recurrent sprain remains the same, but we propose that each of these, including those with recurrent sprain, can exist independently or in combination. The data fit demonstrated that it is possible to have mechanical instability and perceived instability without experiencing recurrent sprain. Previously, this would not have been expected. It should be noted, however, that the numeric values within each cell should not be taken as an indication of the expected prevalence of the different subgroups; they merely indicate that all data from the presented studies fit the model and that subgroups appear to exist. The numeric values noted here reflect the recruitment criteria for the 2 studies. Prevalence of each subgroup should therefore be tested in future research.

Exploring possible associations of different subgroups with different impairments indicates some potential trends. For example, all groups with perceived instability had greater impairment on the foot-lifts test of balance than the hypomobility group. The presence of recurrent sprain appeared to make it more likely that a person could not balance on demipointe when compared with subgroups without recurrent sprain. Finally, perceived instability alone or in combination appeared to be associated with a longer time to recover from an inversion perturbation than was demonstrated by either external controls or participants with ankle hypomobility.

Perceived instability appears to lead to the same degree of impairment as recurrent sprain in some tests, whereas the presence of hypomobility may modulate some effects. Chronic ankle instability has often been defined as the presence of recurrent sprain,[4] with or without perceived instability.[54,58,59] However, 52% of participants in the current study had perceived instability without recurrent sprain. It may be that the feeling of instability is the most

**Table. Fit of Data According to the Proposed Subgroups and Controls[a]**

| Subgroup | Demipointe Test, No. of Failures (%) | Single-Leg Stance Test, No. of Foot Lifts in 30 s (Mean ± SE) | Cohen d[b] | Recovery Time After Perturbation, s (Mean ± SE) | Cohen d[b] |
|---|---|---|---|---|---|
| External controls (n = 42) | 0 (0) | 15.2 ± 1.3 | | 1.55 ± 0.15 | |
| Mechanical instability (n = 3) | 0 (0) | 20.0 ± 7.5 | NA | 2.21 ± 0.46 | NA |
| Perceived instability (n = 30) | 5 (17) | 20.1 ± 1.5 | 0.58 | 2.60 ± 0.19 | 1.05 |
| Recurrent sprain (n = 3) | 0 (0) | 16.7 ± 1.7 | NA | 2.41 ± 0.14 | NA |
| Mechanical instability + perceived instability (n = 7) | 1 (14) | 29.3 ± 4.1 | 1.55 | 3.04 ± 0.41 | 1.45 |
| Mechanical instability + recurrent sprain (n = 1) | 1 (100) | 40.0[c] | NA | 2.52[c] | NA |
| Perceived instability + recurrent sprain (n = 17) | 7 (41) | 25.9 ± 1.9 | 1.32 | 2.56 ± 0.31 | 0.90 |
| Perceived instability + mechanical instability + recurrent sprain (n = 10) | 4 (40) | 25.4 ± 3.2 | 1.10 | 2.58 ± 0.31 | 1.06 |
| Hypomobility (n = 10) | 1 (10) | 18.8 ± 2.9 | 0.42 | 1.67 ± 0.38 | 0.11 |

[a] From Hiller et al.[49,50]

[b] The Cohen d was calculated to compare the effect size for the external controls with that of each subgroup except for groups with 3 or fewer participants (indicated by NA).

[c] With n = 1, SE was not applicable.

prominent factor and is associated with increased severity of some functional impairments, activity limitations, and participation restrictions.

Of interest is that hypomobility, rather than mechanical instability, can also be associated with ankle sprain.[59,60] Hypomobility in the current study appeared to result in either a decrease in degree or even an absence of some impairments. The presence of participants with hypomobility in CAI studies may, therefore, "wash out" significant findings and provide one explanation for inconsistent results. Hypomobility may constitute the basis for an additional subgroup and should be further investigated.

## Impairments Associated With Specific Subgroups

We applied the new model to previously published reports to determine whether similar trends in impairment levels could be better interpreted. A review of ankle-instability research was undertaken and studies were examined when sufficient information was provided about participants' perceived and mechanical instability and recurrent sprains.[4,34,39,45,48,58,61] Criteria for perceived instability included reports of persistent feelings of weakness, instability, or giving way. The specific impairments for which associations with the new subgroups were sought included balance, recovery from an inversion perturbation, and functional tasks.

This further exploration indicated that single-leg balance was impaired in participants with perceived ankle instability but not in those with mechanical instability or in external controls.[34,39,40] Tropp et al[39] found increased postural sway, measured using stabilometry, in participants with both perceived ankle instability and recurrent sprain compared with external controls. Both Konradsen and Ravn[48] and Ryan[34] found differences in postural sway between external controls and participants with either perceived ankle instability alone or perceived ankle instability in combination with mechanical instability. These studies and the current study provide preliminary evidence that perceived instability, when present in any combination, is associated with the ability to balance on a flat foot.

Recovery from an inversion perturbation has also been studied by measuring peroneal reaction times rather than

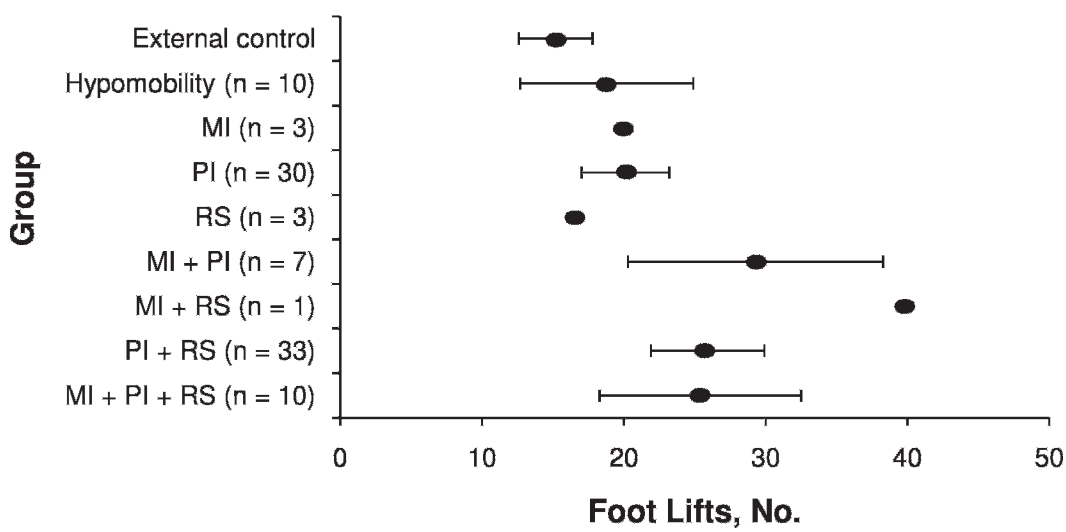


**Figure 4. Forest plot of the foot-lifts balance test in which the number of foot lifts was determined in a 30-second period (mean and 95% confidence intervals for groups with n > 6). Abbreviations: MI, mechanical instability; PI, perceived instability; RS, recurrent sprain.**

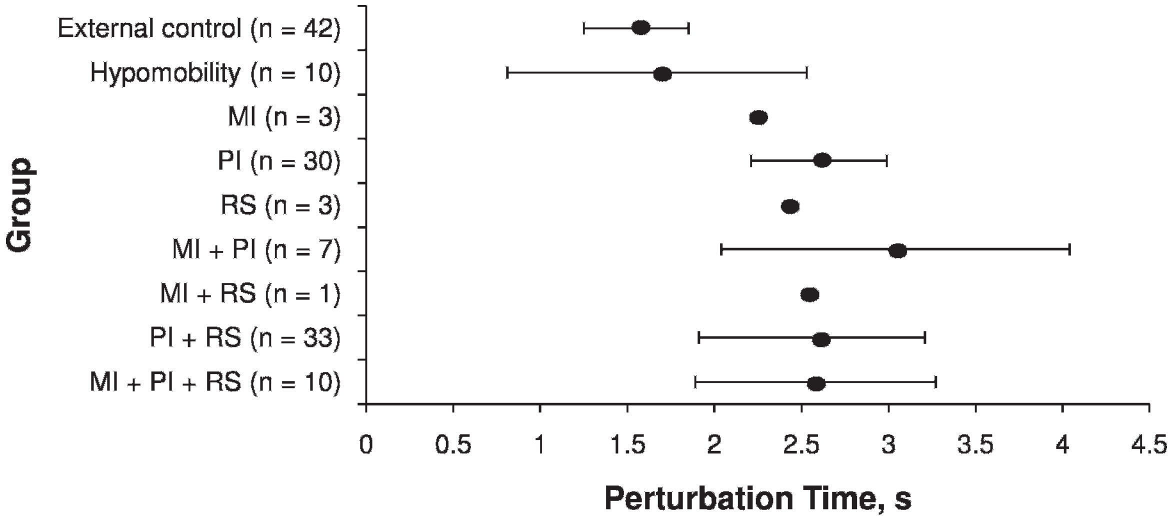


**Figure 5. Forest plot of the time to recover from an inversion perturbation (mean and 95% confidence intervals for groups with n > 6). Abbreviations: MI, mechanical instability; PI, perceived instability; RS, recurrent sprain.**

the protocol we used. Peroneal latency times were similar for external controls and participants with either mechanical instability alone[61] or mechanical instability combined with recurrent sprain.[45] In contrast, latency times were longer for participants with perceived ankle instability combined with either recurrent sprain or mechanical instability than for external controls.[40,45,48] Again, the perceived instability appears to mediate the impairment.

In contrast, in an investigation[58] of ankle motion during functional tasks, patterns of motion were altered in participants with mechanical instability combined with perceived instability but not in either those with perceived instability alone or those who had recovered. In this study, mechanical instability appeared to be a mediating factor. Repeated episodes of giving way or recurrent sprain were inclusion criteria, so it would have been illuminating to divide both the mechanical and functional instability groups into those with and without recurrent sprain.

Taken together, these findings provide preliminary evidence for different associations or levels of impairment with different subgroups. However, although the new model provides preliminary evidence for the proposed subgroups within CAI, it does not resolve all issues. A single test of mechanical instability may not comprehensively detect pathologic laxity of all ankle ligaments. For example, Hubbard et al[62] found no correlation among various tests of mechanical instability in participants with CAI. The tests investigated were fibular position using fluoroscopy, instrumented ankle laxity in 3 directions, and talar hypomobility. Yet in a related study, anterior and inversion laxity were the factors most predictive of CAI group membership,[5] and, therefore, we suggest that at least these 2 directions be considered when assessing mechanical instability.

The definition of *recurrent sprain* also varies widely across studies. A review of the literature shows that definitions of recurrent sprain range from 2 to 8 previous sprains, with various time requirements since the last sprain. It is also unclear whether a lifetime history of 3 sprains separated by a number of years results in the same impairments or activity limitations as a recent history of 3 sprains separated by weeks or months. Finally, giving way of the ankle is often used as an inclusion criterion for studies of CAI. Because giving way can be either perceived or actual, we do not know if it belongs in the current model as part of perceived instability, as a recurrent sprain that does not have a physical response, or as a uniquely different subgroup.

A further interesting question is whether increasing severity of CAI is reflected in a hierarchy in the subgroups. Intuitively, we would expect that people in a subgroup with more components to be more seriously limited in activity and participation than those with only a single component, but this possibility requires further investigation.

## Limitations

The present study had a number of limitations. Testing the model by fitting the data retrospectively means that although all subgroups can be shown to exist, the testing was limited to a single common test for mechanical and perceived instability and recurrent sprain. In particular, mechanical instability was tested only in the anterior-posterior plane using clinical tests (ie, manual testing), although instrumented arthrometry or radiographic measures in at least 2 planes is likely to be more accurate. The model requires validation with a separate group of participants. In addition, research for which participants are recruited using a broad definition of CAI and across a wide range of ages and activity levels would provide a better indication of subgroup prevalence. Specifically, such a study would determine whether it is possible for a participant to have recurrent sprain without mechanical or perceived instability. The retrospective nature of our exploration of impairments also limited the numbers and types of impairment that could be included and the statistical analysis.

## Future Directions

To further our understanding of the impairments, activity limitations, and participation restrictions associated with CAI, we recommend that future authors describe participants using validated measurements of those variables that define the subgroups in both the original and evolved models. We further suggest that hypomobility status be reported to enable exploration of its role in CAI. In this way, homogeneous subgroups will ultimately be defined, enabling identification of the mechanisms causing persistent symptoms and design of specifically targeted treatments. To achieve these goals, we recommend standardized and comprehensive measurement of the relevant variables. Mechanical instability should be tested in at least the anterior-posterior and medial directions. Validated tools, such as the CAIT, should be used for assessing perceived instability, and the number and time frame of recurrent sprains should be recorded. In addition, the number of recent giving-way episodes, both perceived and real, should be noted. We also advise that activity limitation and participation restriction be measured using instruments such as the Foot and Ankle Ability Measure[63] or the Foot and Ankle Outcome Score[64] to increase our understanding of the relationships among subgroup, impairment, and lifestyle changes.

### Clinical Implications

The new model may provide a basis for improved patient care. If different subgroups exhibit different deficits or different severities of deficit, then rehabilitation can be targeted to those deficits. Ultimately, a clinical-prediction rule may be developed to assist clinicians in determining both prognosis and the most efficacious treatment for individual patients.

## CONCLUSIONS

The proposed new model of CAI is supported by data from previous studies. More subgroups have now been identified, and a common link among subgroups in the current study and others is the presence of perceived instability. With our proposed model, greater insight may be possible into the impairments, activity limitations, and participation restrictions in those with CAI. Although it requires further validation, the proposed model is likely to have a significant effect on clinical research and practice because specific rehabilitation and prevention programs can be developed for subgroups of patients with CAI.


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original research

# Changes in Knee Biomechanics After a Hip-Abductor Strengthening Protocol for Runners With Patellofemoral Pain Syndrome

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***Context:*** Very few authors have investigated the relationship between hip-abductor muscle strength and frontal-plane knee mechanics during running.

***Objective:*** To investigate this relationship using a 3-week hip-abductor muscle-strengthening program to identify changes in strength, pain, and biomechanics in runners with patellofemoral pain syndrome (PFPS).

***Design:*** Cohort study.

***Setting:*** University-based clinical research laboratory.

***Patients or Other Participants:*** Fifteen individuals (5 men, 10 women) with PFPS and 10 individuals without PFPS (4 men, 6 women) participated.

***Intervention(s):*** The patients with PFPS completed a 3-week hip-abductor strengthening protocol; control participants did not.

***Main Outcome Measure(s):*** The dependent variables of interest were maximal isometric hip-abductor muscle strength, 2-dimensional peak knee genu valgum angle, and stride-to-stride knee-joint variability. All measures were recorded at baseline and 3 weeks later. Between-groups differences were compared using repeated-measures analyses of variance.

***Results:*** At baseline, the PFPS group exhibited reduced strength, no difference in peak genu valgum angle, and increased stride-to-stride knee-joint variability compared with the control group. After the 3-week protocol, the PFPS group demonstrated increased strength, less pain, no change in peak genu valgum angle, and reduced stride-to-stride knee-joint variability compared with baseline.

***Conclusions:*** A 3-week hip-abductor muscle-strengthening protocol was effective in increasing muscle strength and decreasing pain and stride-to-stride knee-joint variability in individuals with PFPS. However, concomitant changes in peak knee genu valgum angle were not observed.

***Key Words:*** gait, hip muscles, anterior knee pain

**Key Points**

- After a 3-week hip-abduction strengthening program, patients with patellofemoral pain syndrome increased muscle strength and displayed decreases in both pain and stride-to-stride knee-joint variability. No changes were noted in peak knee genu valgum.
- Stride-to-stride knee-joint variability may be a better indicator of injury rehabilitation than are peak angles.
- Hip-abductor muscle strengthening should be incorporated into patellofemoral pain syndrome rehabilitation protocols.

A number of authors[1–7] have hypothesized that a primary contributing factor to patellofemoral pain syndrome (PFPS) is weakness of the hip-abductor musculature. The hip-abductor muscles have been theorized[1–9] to eccentrically control hip adduction and, thus, knee genu valgum angle during the stance phase of running. A greater genu valgum angle (or increase in the dynamic Q-angle) has been purported[2,3,5,8–12] to increase patellofemoral contact pressure and to lead to PFPS. However, very few researchers have investigated the relationship between hip-abductor muscle strength and frontal-plane knee mechanics.

Willson and Davis[11] reported that compared with controls, patients with PFPS exhibited greater hip adduction during single-leg squats, running, and repetitive single-leg jumps, and they attributed the atypical frontal-plane mechanics to weakness of the hip-abductor musculature. However, measures of hip-abductor strength were not collected. Other authors[7–10,13] have also reported similar findings, with PFPS patients demonstrating greater hip adduction, knee genu valgum, or reduced strength of the hip-abductor musculature (or all of these) than do healthy people. Yet these studies mainly investigated each variable in isolation and did not directly address the relationship between hip-abductor muscle strength and knee genu valgum angle.

Few experts have examined the relationship between hip-abductor muscle strength and knee mechanics and how gains or reductions in strength may affect frontal-plane knee mechanics. Bolgla et al[7] measured hip-abductor strength and knee and hip kinematics and reported that those with PFPS exhibited reduced hip-abductor muscle strength but no differences in knee genu valgum angle during stair descent compared with the control group. Similar to Bolgla et al,[7] Dierks et al[2] reported reduced hip-abductor muscle strength in both PFPS patients and the control group after a prolonged and exhaustive run. However, in contrast to the findings of Bolgla et al,[7] the PFPS patients in this study exhibited an increase in peak hip adduction, a component of the knee genu valgum angle, over the course of the run, compared with healthy runners. Recently, Snyder et al[14] reported that after a 6-week hip strengthening protocol, healthy female runners exhibited a 13% gain in abductor strength, but the hip-adduction angle during running increased by 1.4°, contrary to their hypotheses and the results of previous studies. Moreover, to date, no authors have specifically tested whether improvements in muscle strength would lead to a reduced peak knee genu valgum angle for runners with PFPS. Thus, based on the conflicting results of these studies, further investigation into the relationship between hip-abductor muscle strength and knee mechanics is warranted. In light of these contradictory findings in the literature, it may be worthwhile to examine the relationship between hip-abductor muscle strength and knee mechanics using a more novel approach.

Previous authors[15–21] have suggested that movement variability may be an important consideration with respect to injury prevention and rehabilitation. However, one must first define *movement variability*. When a motion is performed repeatedly, as in the stride-to-stride pattern involved in running, and even when the goal of the motion remains constant, the exhibited kinematic movement pattern varies among strides.[17] The overall movement goal of running would be an example of *global variability*, which has been defined as a combination of between-limbs or within-limb kinematic patterns for the purpose of a movement goal or, for example, in response to balance perturbations. In contrast, *local variability* has been defined as the coupling or relative angles between joints or segments.[15]

Stride-to-stride variability in joint movement patterns during locomotion can be both beneficial and harmful depending on the global or local variability measure used. For example, increased stride-to-stride variability in stride length[18] and stride time,[19] both measures of global variability, have been associated with an increased risk of falling. With respect to local variability, in 2009 Drewes et al[20] reported less coordinated rearfoot-shank segmental coupling in those with chronic ankle instability, and McKeon et al[21] observed a decrease in rearfoot-shank segmental coupling variability in individuals with chronic ankle instability after a 4-week balance-training program. Miller et al[17] suggested that during running, tibia-rearfoot and rearfoot-thigh segmental coupling variability was reduced, but knee-rearfoot coupling variability was increased in runners with a history of iliotibial band syndrome, compared with healthy individuals. Finally, Hamill et al[15] noted less variability in lower extremity movement patterns during running in patients with PFPS compared with healthy people. Thus, although there is some discrepancy in the literature, most researchers have reported that reduced variability is associated with running-related injuries, such as PFPS, and increased variability of movement appears to be necessary to allow for flexibility in gait mechanics in response to unexpected perturbations.

The purpose of our experiment was to investigate the relationship between hip-abductor muscle strength and frontal-plane knee mechanics. We sought to assess this relationship by using a 3-week hip-abductor muscle-strengthening protocol to measure potential changes in strength, pain, and biomechanics in patients with PFPS. We operationally defined local, within-limb movement variability and quantified it as the change in knee-joint frontal-plane kinematic patterns across 10 consecutive footfalls (herein called *stride-to-stride knee-joint variability*). We hypothesized that at baseline, PFPS patients would exhibit reduced hip-abductor muscle strength, greater peak knee genu valgum angle, and decreased stride-to-stride knee-joint variability compared with the control group. After the 3-week rehabilitation protocol, we hypothesized that hip-abductor muscle strength would increase, pain would decrease, peak knee genu valgum angle would decrease, and stride-to-stride knee-joint variability would increase over baseline measures.

## METHODS

### Participants

We conducted an a priori sample-size power analysis ($\beta$ = .20, $\alpha$ = .05; desired effect size = 0.66) using variability in hip-abductor strength and knee genu valgum data obtained from pilot data and relevant literature.[8,11,14,22] Based on this analysis, a minimum of 10 to 13 participants per group were needed to adequately power the study based on the variables of interest. Specifically, 10 individuals were needed to adequately detect differences in hip-abductor strength,[11,14] and at least 13 people were needed to adequately detect differences in peak knee genu valgum angle,[8,14,22] either compared with the control group or after a strengthening protocol. Each participant signed a consent form approved by the University of Calgary Conjoint Health Research Ethics Board, which also approved the study.

All participants were active recreational athletes running at least 30 minutes per day a minimum of 3 days per week. The PFPS group consisted of 5 men and 10 women (age = 35.2 ± 12.2 years, height = 1.65 ± 0.34 m, mass = 69.1 ± 11.6 kg). The control group consisted of 4 men and 6 women (age = 29.9 ± 8.3 years, height = 1.73 ± 0.41 m, mass = 73.1 ± 15.7 kg). The control volunteers were pain free at the time of testing, had no history of orthopaedic surgery, had not sustained a musculoskeletal injury in the past year, and did not meet any of the exclusion criteria.

The PFPS participants presented to the clinic and were assessed by the same certified athletic trainer for exclusion criteria. Exclusion criteria were consistent with those of Boling et al[12] and included unilateral symptoms present for more than 2 months, self-reported clinical evidence of other knee conditions, history of knee surgery, self-reported history of patellar dislocations or subluxations, or current significant injury affecting other lower extremity joints. The PFPS injury assessment was also based on that of Boling et al[12] and included anterior or retropatellar knee pain, with a severity of at least 3 on a 10-cm visual analogue scale (VAS), during at least 2 of the following activities and within the past week: (1) ascending and descending stairs, (2) hopping and running, (3) squatting or kneeling, and (4) prolonged sitting. The PFPS individuals also had to exhibit insidious onset of symptoms unrelated to trauma, pain with compression of the patella, and pain on palpation of patellar facets.

## Procedures

Retroreflective markers were used to measure 2-dimensional (2-D) knee frontal-plane biomechanical motion. The markers were secured to hook-and-loop straps that were tightly wrapped around the thigh and shank to minimize movement artifact and along a line between the ischial tuberosity and the middle of the popliteal fossa and between the middle of the popliteal fossa and the Achilles tendon to represent the long axes of the femur and shank, respectively (Figure 1). After collecting a 1-second standing calibration trial, volunteers performed dynamic trials in which they ran on a treadmill (model TR 4500, Star Trac, Irvine, CA) for 20 seconds (approximately 30 footfalls) at a speed of 2.55 m/s. We chose this speed because previous authors[2,11,15–17,23] have reported using similar overground and treadmill speeds. A 2-minute warm-up period provided time for accommodation to the treadmill and speed and to achieve a steady state of comfortable running before the 20 seconds of data were collected. All participants were familiar with treadmill running. The middle 10 consecutive footfalls were selected and analyzed from the symptomatic limb for the PFPS group and from the dominant limb for the control group.

Strength of the hip-abductor muscles was measured with the side-lying volunteer exerting a maximal isometric contraction for 5 seconds in 30° of hip abduction and 5° of hip extension.[24] A force dynamometer (model 01163 manual muscle tester; Lafayette Instrument, Lafayette, IN) was used to measure force output. The dynamometer was placed immediately proximal to the lateral malleolus, and participants applied a maximal isometric force against a nonelastic strap for the "make" test method of strength testing.[3] An initial familiarization trial was performed before the average of 3 trials was recorded; all trials were within a coefficient of variation of 10%. Body weight was measured using a standard digital scale, and force values were normalized to a percentage of body weight. Pain was measured using a 10-cm VAS. All measurements were taken at baseline and at 3 weeks for both the control and PFPS volunteers.

## Rehabilitation Protocol

All PFPS patients were given a 3-week hip-abductor muscle-strengthening protocol consisting of 2 exercises (Figure 2). These exercises were to be performed using a 5-ft (1.52-m) piece of Resist-A-Band (Donovan Industries, Inc, Tampa, FL) for 3 sets of 10 repetitions of each exercise, for each leg, daily over the course of the 3 weeks. The patients were instructed to move the involved limb outward for 2 seconds and inward for 2 seconds and to exercise both limbs using this common therapeutic protocol because the contralateral limb also benefits from the exercise.[25] All PFPS patients returned after 7 to 10 days for a follow-up to log exercise program adherence and to have their exercise technique checked. If the sets and repetitions were being performed too easily, a piece of band offering greater resistance was provided. The PFPS participants were asked to refrain from any therapeutic treatments other than the 2 exercises, and all volunteers were encouraged to continue with their regular running schedule at their discretion. It is important to note that all PFPS patients were running on a regular basis at the time of data collection.

**Figure 1. Retroreflective marker placement used for kinematic data collection.**

## Data Collection and Analysis

Pain was measured using a VAS in which 0 indicated *no pain* and 10 indicated *the most pain imaginable*. The PFPS participants were asked to place a dash along the 10-cm line to indicate the average amount of pain experienced during the past week while running.

Kinematic data were collected using a 60-Hz camera (model GL2; Canon Canada Inc, Mississauga, ON, Canada). For all data collection, the camera was placed 1.2 m above the ground and 1.7 m away from the middle of the treadmill. A digital inclinometer (model 360; SmartTool Technology, Inc, Oklahoma City, OK) ensured that the camera lens was oriented parallel to the frontal plane of the laboratory and the participant and perpendicular to the treadmill platform. Raw marker trajectory data were filtered with a second-order, low-pass Butterworth filter at 10 Hz. Vicon Motus software (version 9.2; C-Motion, Inc, Rockville, MD) was used to digitize the markers and filter and to calculate 2-D angles. The kinematic data were analyzed for the stance phase and normalized to 101 data points. The stance phase was determined using kinematic marker data, with initial contact identified using a velocity-based algorithm applied to the posterior calcaneus, and

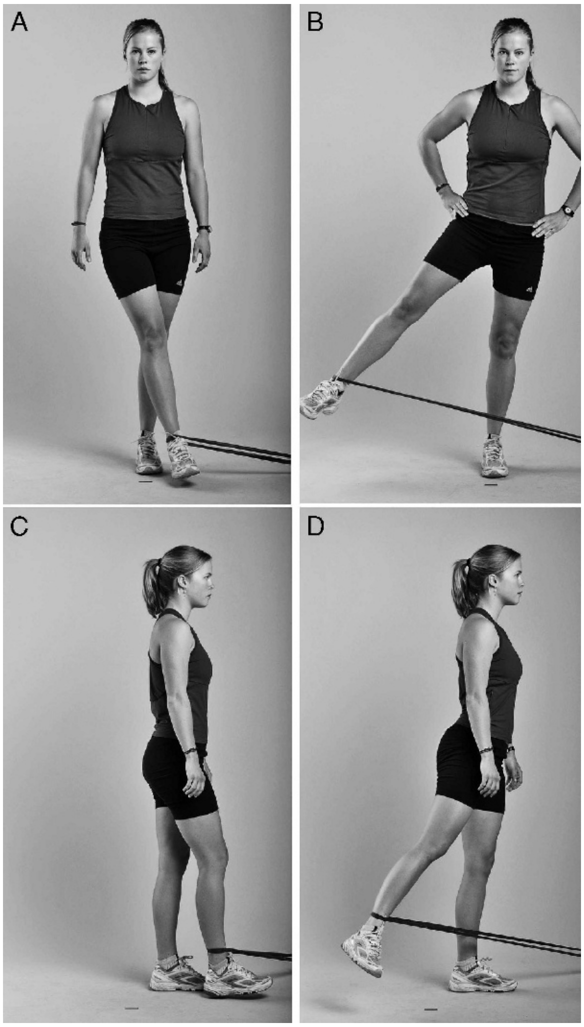


**Figure 2. The 2 hip-abductor muscle-strengthening exercises performed by the patellofemoral pain syndrome group. A, B, In the first exercise, the patient moves the involved leg outward, keeping the knee straight. C, D, In the second exercise, the patient moves the involved leg back to a 45° angle, keeping the knee straight and the pelvis stable.**

toe-off was defined with visual inspection.[26] Maximal isometric hip-abductor strength measures were normalized to each volunteer's body weight.

The specific kinematic variables of interest from 10 consecutive footfalls used for statistical analysis were peak knee genu valgum angle and stride-to-stride knee-joint variability. Knee genu valgum angle was calculated as the angle subtended by the line connecting the 2 thigh-segment markers and the line connecting the 2 shank markers. The *peak angle* was defined as the largest valgus angle measured after footstrike and generally occurred during the midstance portion of stance. Previous authors have shown this 2-D approach to be valid (errors < 1.7°) and moderately reliable for side-step ($r$ = 0.58) and side jump ($r$ = 0.64) maneuvers, compared with 3-dimensional (3-D) methods,[27] and data from our laboratory show this 2-D measure to be valid (errors < 1.8°) and highly reliable compared with 3-D treadmill running data ($r$ = 0.86).

Measurement of knee frontal-plane stride-to-stride variability was based on earlier studies,[28,29] using a Pearson product moment correlation coefficient on a stride-to-stride basis over the 10 consecutive footfalls. Specifically, the temporal pattern of knee genu valgum for the first footfall was compared on a point-by-point basis with the subsequent footfall (ie, footfall 1 was compared with footfall 2) for all 101 points of data and across the 10 consecutive footfalls. Thus, using this method, a total of 9 stride-to-stride comparisons occurred for each volunteer and were then averaged for analysis. Values of $r$ = 1.0 indicate perfectly matched kinematic patterns and no stride-to-stride variability; values closer to $r$ = 0.0 indicate greater temporal asynchrony and increased variability.

### Statistical Design

We used a 2 × 2 repeated-measures design and analysis of variance to identify changes in the dependent variables of interest: (1) peak isometric hip-abduction force, (2) peak knee genu valgum angle, and (3) stride-to-stride knee-joint variability. The independent variables were group (PFPS, control) and time (pretest, posttest). Statistical analysis was performed with SPSS (version 17.0; SPSS Inc, Chicago, IL). Tukey post hoc tests were performed to identify significant differences, if any, when appropriate. Alpha was set at .05 for all analyses.

## RESULTS

No differences were measured between groups for age ($P$ = .44), height ($P$ = .46), or mass ($P$ = 0.32). A summary of the variables of interest at the pretest and posttest is presented in the Table. At baseline, the PFPS group's hip-abductor muscle strength was 28.71% less than that of controls ($P$ = .01; Figure 3). No differences ($P$ = .67) in peak genu valgum angle were noted between groups. Stride-to-stride knee-joint variability for the PFPS group was less than for the control group ($P$ = .01; Figure 3).

The PFPS patients were compliant with the rehabilitation protocol and completed the exercises, on average, 6.2 days per week over the 3 weeks. At the posttest, their isometric muscle strength had increased 32.69% over baseline values ($P$ = .04). However, compared with the control group, no difference in muscle strength ($P$ = .33) was evident. The PFPS patients displayed a 43.10% reduction in VAS score ($P$ = .01) after the rehabilitation protocol. No differences in peak genu valgum angle were measured at the posttest, compared with baseline values ($P$ = .55) or the control group ($P$ = .65). Stride-to-stride knee-joint variability curves for the PFPS group increased compared with baseline ($P$ = .01; Figure 3), but no differences from the control group were measured ($P$ = .36).

No differences in maximal isometric strength ($P$ = .87), peak knee genu valgum angle ($P$ = .51), or stride-to-stride knee-joint variability ($P$ = .84) were found between testing sessions for the control group.

## DISCUSSION

Our purpose was to investigate the relationship between hip-abductor muscle strength and frontal-plane knee mechanics. We used a 3-week hip-abductor muscle-strengthening protocol to measure potential changes in strength, biomechanics, and pain for patients experiencing PFPS. Previous authors[1–7] have hypothesized that a primary contributing factor to PFPS is weakness of the

**Table. Variables of Interest for the Control and Patellofemoral Pain Syndrome Groups**

| | Control Group | | | | Patellofemoral Pain Syndrome Group | | | |
|---|---|---|---|---|---|---|---|---|
| | Pretraining | | Posttraining | | Pretraining | | Posttraining | |
| Variable | Mean ± SD | 95% Confidence Interval | Mean ± SD | 95% Confidence Interval | Mean ± SD | 95% Confidence Interval | Mean ± SD | 95% Confidence Interval |
| Abductor muscle strength, % of body weight | 18.11 ± 3.89 | 15.15, 21.07 | 18.49 ± 2.99 | 15.76, 21.22 | 12.91 ± 4.12[a] | 9.89, 15.93 | 17.13 ± 3.08[b] | 14.37, 19.89 |
| Genu valgum, ° | 2.67 ± 1.19 | 0.40, 4.94 | 3.1 ± 1.02 | 0.88, 5.32 | 3.71 ± 1.38 | 1.39, 6.03 | 3.05 ± 1.34 | 0.74, 5.36 |
| Consecutive footfall variability, *r* | 0.81 ± 0.17 | 0.75, 0.87 | 0.83 ± 0.15 | 0.78, 0.88 | 0.39 ± 0.11[a] | 0.35, 0.43 | 0.79 ± 0.13[b] | 0.75, 0.83 |
| Visual analogue scale pain score, cm | | | | | 5.80 ± 2.10 | 5.10, 6.50 | 3.30 ± 1.90[b] | 2.67, 3.93 |

[a] Value reduced compared with control group ($P < .05$).
[b] Value increased compared with prerehabilitation values ($P < .05$).

hip musculature, including the abductors. However, few researchers have directly investigated this possibility.

In support of the first hypothesis, the PFPS patients exhibited 28.71% reduced maximal isometric hip-abductor muscle strength at baseline, compared with the control group. These results are similar to those of several other studies[1–9,12,15–18] involving PFPS patients and indicate that weakness of the hip abductors may play a key role in the development of PFPS. We also hypothesized that over the 3-week rehabilitation protocol, hip-abductor muscle strength would increase. In support of this hypothesis, PFPS patients exhibited an average 32.69% improvement in strength. Authors of earlier strengthening studies[6,14,30–32] reported 13% to 51% increases in hip-abductor strength after rehabilitation protocols that ranged from 6 to 14 weeks in length. Thus, the increase in abductor strength reported in the current study is comparable with previous findings.

We hypothesized that over the 3-week rehabilitation protocol, the level of pain experienced by the PFPS patients would decrease. In support of this hypothesis, the level of pain for 14 of the 15 patients decreased 40% over the course of the study. These results are in agreement with those of previous studies[1–9,12,15–18] whose authors also suggested that hip-abductor muscle weakness is a contributing factor in the development and treatment of PFPS and should be targeted in its treatment. An asset of our investigation is that the rehabilitation protocol consisted of exercises intended solely to increase the strength of the hip abductors. Thus, these results provide further evidence that hip-abductor muscle-strengthening exercises should be considered for preventing musculoskeletal injury and treating PFPS.

Tyler et al[32] examined the benefits of a hip-strengthening program on 35 patients diagnosed with PFPS. All volunteers participated in a 6-week intervention that consisted primarily of hip-strengthening exercises. Hip strength improved in 66% of the PFPS patients, which is consistent with our results. Based on a minimum decrease of 1.5 cm in the VAS scores, 21 patients (26 knees) had a successful outcome and 14 patients (17 knees) had an unsuccessful outcome. Interestingly, and in contrast to our results, these authors[32] reported that, based on their statistical analysis, improvement in hip-abduction strength was unrelated to PFPS pain and treatment outcome. Thus, other muscles in addition to the hip abductors may be important in treating PFPS.[31,32] Future studies involving a more comprehensive hip muscle-strengthening protocol are necessary to answer this question.

In such a short period of time, improvements in muscle strength are largely attributable to changes in neuromuscular activation of muscles and not to changes in muscle-fiber composition or hypertrophy.[33,34] Previous authors[33,34] have shown that after 10 or 14 days of daily strengthening, an increased number of motor units are recruited, concomitant with greater maximal voluntary contraction. These results support the notion that neural adaptation, not hip-abductor muscle-fiber hypertrophy, was primarily responsible for the increased strength exhibited by the PFPS participants after only 3 weeks of muscle strengthening.

Similar to earlier researchers,[2,3,8,9,11] we hypothesized that reduced hip-abductor muscle strength would result in a greater peak knee genu valgum angle when running and, thus, would contribute to the development of PFPS, because the hip abductors would not be able to adequately control hip adduction via eccentric contraction. However, no differences in peak knee genu valgum angle were measured between groups or across time.

To date, few investigators[2,6,7,14] have evaluated the relationship between hip-abductor muscle strength and knee kinematics. Our findings are similar to those of Bolgla et al,[7] who reported that 18 patients with PFPS had hip weakness but did not demonstrate altered hip or knee kinematics while descending stairs, compared with a control group. Yet our results contrast with those of Mascal et al.[6] In their case study, the participant who underwent a biomechanical assessment after a 14-week strengthening protocol demonstrated improved hip strength and reduced hip adduction (a component of knee genu valgum) during a step-down maneuver, compared with baseline values. Our findings also contrast with those of Dierks et al,[2] who reported an inverse relationship between decreased hip-abductor muscle strength and increased hip adduction at the beginning and end of a prolonged run for PFPS patients.

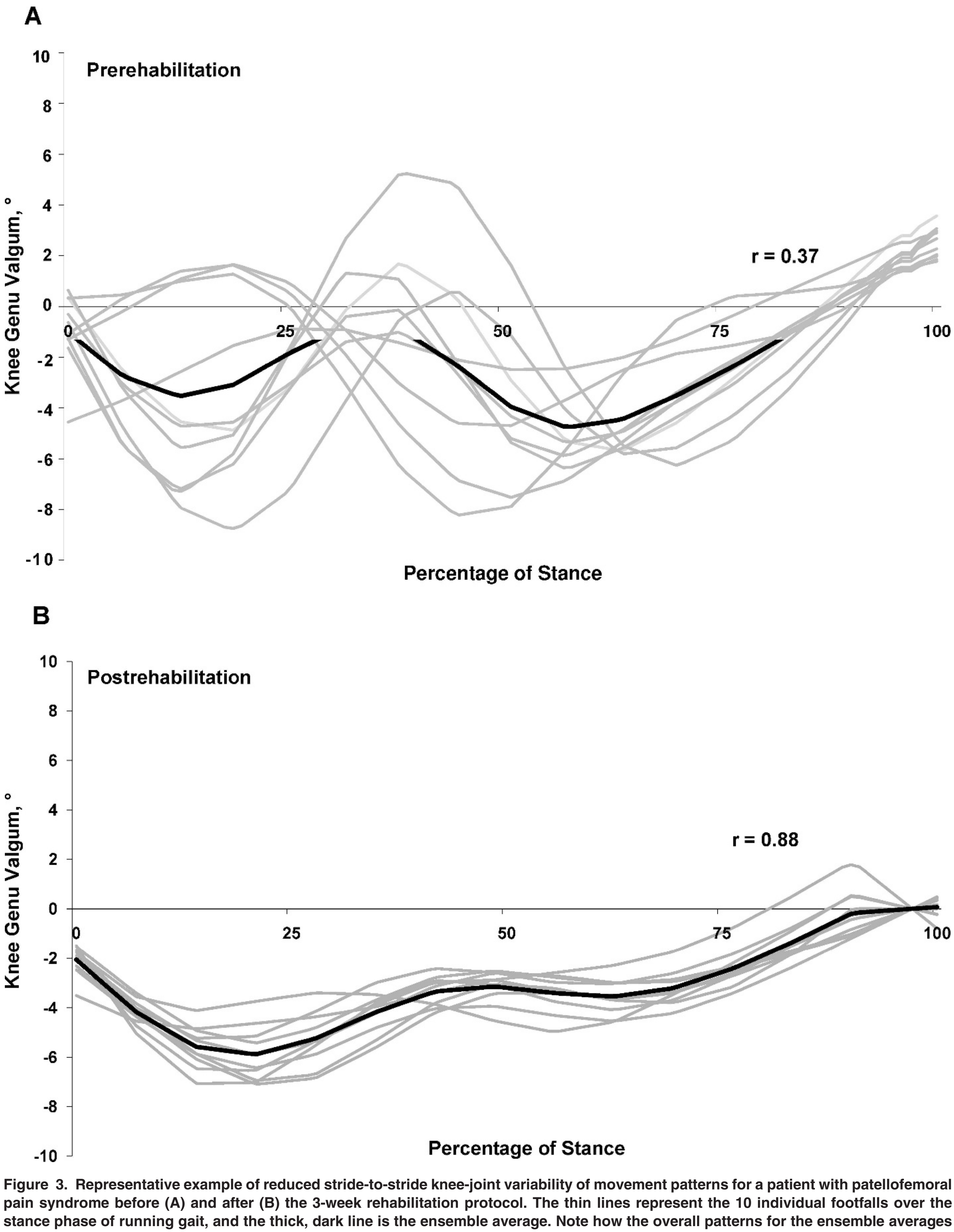


**Figure 3. Representative example of reduced stride-to-stride knee-joint variability of movement patterns for a patient with patellofemoral pain syndrome before (A) and after (B) the 3-week rehabilitation protocol. The thin lines represent the 10 individual footfalls over the stance phase of running gait, and the thick, dark line is the ensemble average. Note how the overall patterns for the ensemble averages are similar, thus contributing to no measured differences in peak knee genu valgum angle.**

The single-subject design and stair-descent method used by Mascal et al[6] make comparison of their results with ours difficult. We measured 2-D knee genu valgum angle, which is a combination of thigh adduction and shank abduction. Thus, comparison with studies of 3-D angles is challenging. In addition, Dierks et al[2] used a fatigue protocol to determine the association between hip-abductor muscle strength and mechanics, whereas we used a muscle-strengthening protocol. Future studies are therefore necessary to help resolve these conflicting data.

Based on the PFPS data reported by Hamill et al[15] and others, we hypothesized that over the 3-week rehabilitation protocol, stride-to-stride knee-joint variability would increase as pain-free status and more typical movement patterns were restored. However, at baseline we measured a marked increase in variability for the PFPS group compared with the control group. Moreover, we measured reductions in stride-to-stride knee-joint variability after the strengthening protocol.

Inspection of Figure 3 reveals that the PFPS group adopted a more consistent stride-to-stride kinematic pattern after the rehabilitation protocol. From a clinical perspective, it is reasonable to assume that restoring a more consistent and predictable movement pattern, concomitant with increased muscle strength and reduced pain, would be expected after such an exercise regime. By providing the knee joint with more consistent (ie, less variable) movement patterns on a stride-to-stride basis, it is possible that a more optimal environment is established, allowing for tissue healing and pain resolution. Additional clinical studies are necessary to answer these questions.

It is important to compare the methods used by Hamill et al[15] with ours. They investigated intersegment coupling variability, whereas we assessed variability within a single joint. They theorized that increased movement variability from 2 lower extremity segments represents a healthy population and is necessary to help prevent injury. This theory can still be applied to our results because increased intersegmental coupling between the shank and thigh may have produced our observed reduction in single-joint motion. More research will address this question.

At the posttest, compared with their baseline values, all 15 PFPS patients increased muscle strength and demonstrated at least a 4-cm (33%) VAS drop in pain; in fact, 4 patients were pain free at 3 weeks. Reduced stride-to-stride knee-joint variability was seen in 13 of 15 patients. At the end of the study, we provided all patients with a more comprehensive rehabilitation program, including recommendations for stretching and strengthening exercises that focused on the low back, hip, knee, and ankle musculature. Anecdotally, we followed up after an additional 3 weeks of rehabilitation and learned that all patients were pain free and had returned to their preinjury running regimes.

Several limitations of this study are apparent. First, the biomechanical measures used a 2-D camera system, and knee motion occurs in 3 dimensions. Thus, using a 3-D motion system would provide more comprehensive data regarding the changes in pelvic and lower limb mechanics that occur as a result of muscle strengthening. However, previous authors[27] have shown this 2-D approach to be valid and moderately reliable for side-step and side-jump maneuvers, and data from our laboratory show this 2-D measure to be valid and highly reliable compared with 3-D measures during treadmill running. The control group exhibited no change in peak knee genu valgum angle over the 3 weeks, results similar to those of earlier investigations.[7,14,22] For example, Snyder et al[14] reported 0.4° and 1.4° changes in knee-abduction and hip-adduction excursion values, respectively, after a 6-week strengthening protocol. Moreover, the 0.66° and 0.43° differences we measured for the PFPS and control groups, respectively, are similar to those reported by Ferber et al,[22] who investigated 3-D kinematics for test-retest reliability in healthy runners. These authors reported mean differences of 0.64° in peak knee adduction and 1.64° in peak hip adduction over 2 days. Thus, even though we used a 2-D analysis, our results are comparable with those of previous 3-D studies.

Second, because we had a standard camera placement and did not position it at a specific height from the ground relative to the participant's height or knee location (or both), perspective error was a possibility. However, our volunteers were all of the same approximate height, and given that our day-to-day values were similar to those of an earlier investigation,[22] we are confident that this concern was minimized. Next, the investigator was aware of the participant's group allocation (PFPS or control), and only the PFPS group performed the exercises, perhaps leading to bias during testing and analysis. However, using a standardized protocol for data collection and analysis for each measure reduced this bias. Also, future research involving a PFPS group that did not perform the exercises would be helpful to better understand how the exercises and subsequent increases in hip-abductor muscle strength influenced movement mechanics. In addition, the groups were not matched for number of participants or sex. However, no differences in age, height, or mass were measured between the groups, and all study participants were recreational runners, indicating that the groups were similar. The volunteers performed a simple running task that lasted a relatively brief period of time, and all ran at the same speed. This procedure may not have been strenuous enough to reveal changes in lower extremity mechanics, so future studies involving running to fatigue, similar to the protocol of Dierks et al,[2] may be beneficial. Furthermore, the running speed chosen was a comfortable pace for all participants and was similar to their own regular running paces on a treadmill and compared with previous studies. Next, the number of patients and length of the rehabilitation protocol were limited. A study with a larger control population matched for age, sex, mass, and mileage or a longer and more comprehensive rehabilitation protocol (or both) may reveal different results, especially with respect to changes in knee genu valgum mechanics. Lastly, we measured isometric muscle-force output, which is not a direct measure of hip-abductor muscle strength and does not necessarily reflect the dynamic concentric and eccentric muscle contractions involved in running.

## CONCLUSIONS

A 3-week hip-abductor muscle-strengthening protocol was effective in increasing muscle strength and decreasing the level of pain and stride-to-stride knee-joint variability in individuals with PFPS. These results also indicate that stride-to-stride knee-joint variability may be a better indicator of injury rehabilitation progression than are peak angles. Finally, incorporating hip-abductor muscle-strengthening into PFPS rehabilitation protocols is important.


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original research

# Interday Reliability of Peak Muscular Power Outputs on an Isotonic Dynamometer and Assessment of Active Trunk Control Using the Chop and Lift Tests

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***Context:*** Assessment techniques used to measure functional tasks involving active trunk control are restricted to linear movements that lack the explosive movements and dynamic tasks associated with activities of daily living and sport. Reliable clinical methods used to assess the diagonal and ballistic movements about the trunk are lacking.

***Objective:*** To assess the interday reliability of peak muscular power outputs while participants performed diagonal chop and lift tests and maintained a stable trunk.

***Design:*** Controlled laboratory study.

***Setting:*** University research laboratory.

***Patients or Other Participants:*** Eighteen healthy individuals (10 men and 8 women; age = 32 ± 11 years, height = 168 ± 12 cm, mass = 80 ± 19 kg) from the general population participated.

***Intervention(s):*** Participants performed 2 power tests (chop, lift) using an isotonic dynamometer and 3 endurance tests (Biering-Sørensen, side-plank left, side-plank right) to assess active trunk control. Testing was performed on 3 different days separated by at least 1 week. Reliability was compared between days 1 and 2 and between days 2 and 3. Correlations between the power and endurance tests were evaluated to determine the degree of similarity.

***Main Outcome Measure(s):*** Peak muscular power outputs (watts) derived from a 1-repetition maximum protocol for the chop and lift tests were collected for both the right and left sides.

***Results:*** Intraclass correlation coefficients for peak muscular power were highly reliable for the chop (range, 0.87–0.98), lift (range, 0.83–0.96), and endurance (range, 0.80–0.98) tests between test sessions. The correlations between the power assessments and the Biering-Sørensen test ($r$ range, −0.008 to 0.017) were low. The side-plank tests were moderately correlated with the chop ($r$ range, 0.528–0.590) and the lift ($r$ range, 0.359–0.467) tests.

***Conclusions:*** The diagonal chop and lift power protocol generated reliable data and appears to be a dynamic test that simulates functional tasks, which require dynamic trunk control.

***Key Words:*** trunk stability, anaerobic peak muscular power, assessment, diagonal movement patterns

**Key Points**

- Peak muscular power outputs (measured in watts) obtained from the chop and lift tests were highly reliable across different test days separated by at least 1 week.
- The chop and lift tests were novel but reliable measurements for dynamic, multiplanar functional activities that have low to moderate correlation with traditional muscular endurance tests, indicating that these tests provide unique information about function compared with traditional measures.
- Performing diagonal power movements about a stable trunk can offer clinicians alternate tests that simulate activities of daily living and sport in a dynamic nature.

Functional tasks in activities of daily living and sport require some dynamic trunk activity.[1,2] The trunk musculature absorbs, produces, and transports multidirectional forces to and from the upper and lower extremities by maintaining a balance of stability and mobility.[3–5] The importance of maintaining and controlling different positions of the trunk during physical activity has been well established in the functional performance and injury literature.[6–12] Researchers have hypothesized that deficits in muscular capabilities (power, strength, endurance) and motor control (amplitude, timing) lead to poor trunk stabilization and can alter performance or increase injury susceptibility.[10,13–17] As a result, several different assessment techniques have emerged to evaluate trunk musculature. Unfortunately, most of these assessment techniques focus on muscular endurance tasks and evaluate static postures[18–20] or linear movements.[21] Recently, investigators[22,23] identified muscular power as a critical element in the development and evaluation of proximal stability for dynamic trunk activity. Power movements, such as lifting a heavy bag of pet food out of the car or throwing or kicking a ball, rely on a proximal foundation.[5,24,25] Some researchers[16,17] consider diagonal and forceful movement patterns that simulate motions associated with activities of daily living or sport to be more functionally appropriate in assessing the capabilities of the trunk stabilizers. To date, limited reliable assessment tests are available to evaluate active trunk control with diagonal and forceful movements similar to activities of daily living and sport.

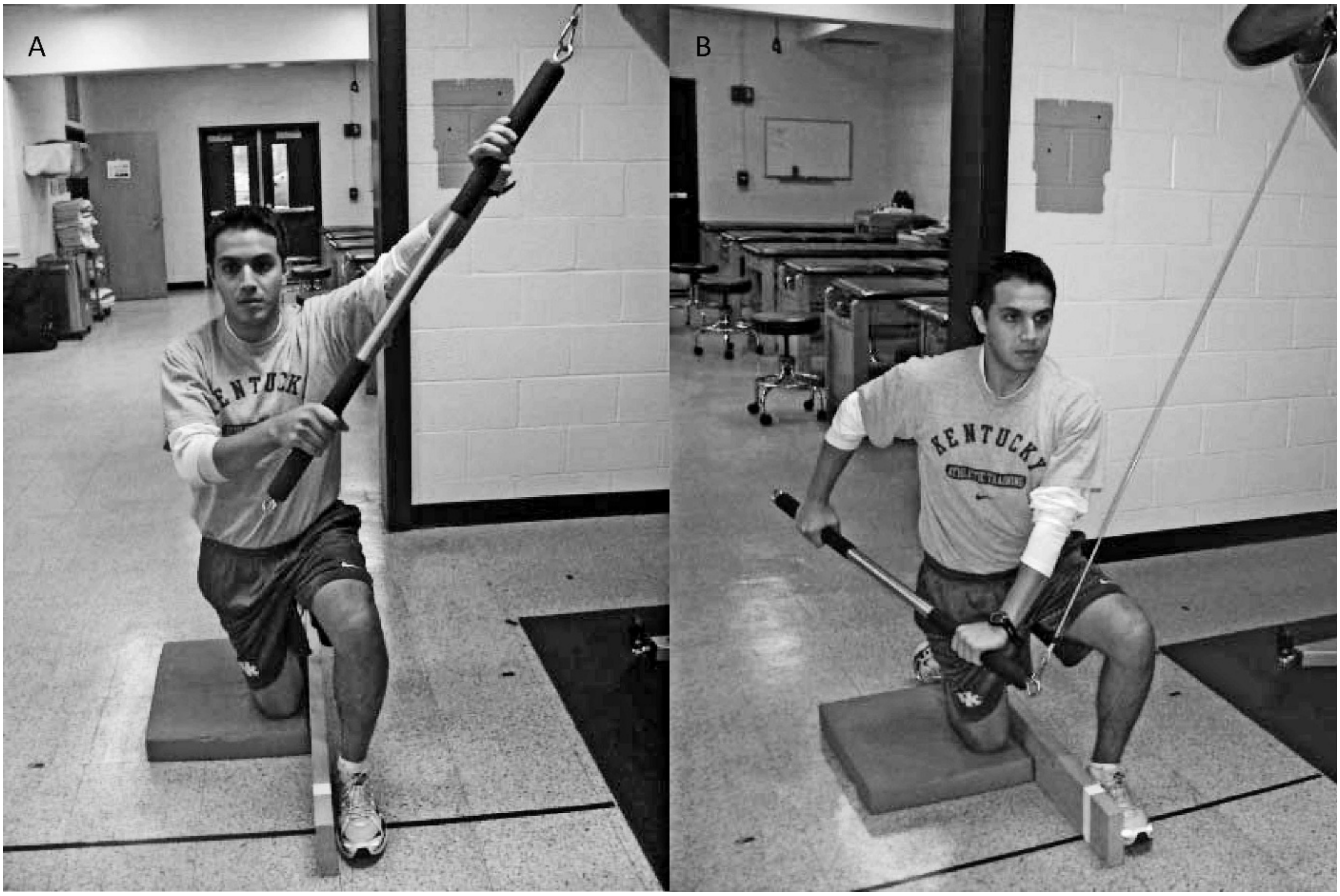


**Figure 1. Chop test, right. The diagonal chopping motion moves across the torso in a downward direction from left to right. A, Beginning position. B, Ending position.**

Described as bilateral modified proprioceptive neuromuscular facilitation exercises, the half-kneeling chop and lift tests use upper extremity multiplanar motions to assess or train shoulder and trunk musculature (Figures 1 and 2).[4,17] Combined with an explosive-power output measure, these maneuvers could provide a novel way to assess diagonal forceful movement that mimics the activities of daily living and demands seen in some sports. No researchers have assessed the repeatability of the chop and lift tests to measure peak muscular power capabilities. Therefore, the primary purpose of our study was to evaluate the interday reliability of peak muscular power output measures using diagonal chop and lift tests among the general population. We hypothesized that 1-repetition maximum (1RM) peak muscular power outputs produced during the chop and lift tests would be reliable between days. Our secondary purpose was to examine the relationship between the chop and lift tests and the traditional plank endurance tests. Because of the dynamic and static nature of the tests, we anticipated that the correlations between the tests would be low to moderate ($<0.75$).[26]

## METHODS

### Participants

Eighteen healthy volunteers from a general population (10 men and 8 women; age = 32 ± 11 years, height = 168 ± 12 cm, mass = 80 ± 19 kg) took part in the trunk-stability assessment sessions. Inclusion criteria were set to anyone between ages 18 and 65 years. Individuals reporting (1) any major orthopaedic injury (upper or lower extremity, torso, spine) 3 months before the study that resulted in dysfunction or time missed from performing daily activities or (2) cardiovascular or neurologic diseases, infections, tumors, osteoporosis, spondylolysis, spondylolithesis, or injury to the vertebrae or discs were excluded from the study. Participants provided their current physical activity levels using a modified Tegner activity scale (range, 1–10), with 1 representing *low activity level* and 10 representing *high activity level*.[27] The study population represented a wide cross section of activity levels on the Tegner scale (mean, 5 ± 2; range, 2–9). All participants were instructed to maintain the same activity level until the completion of the study. They provided written informed consent, and the study was approved by the institutional review board of the University of Kentucky.

### Testing Procedures

Testing was performed in the Musculoskeletal Laboratory at the University of Kentucky. All testing sessions included both power and endurance tests performed on the same day and were completed in approximately 1 hour. Each set of tests required approximately 20 minutes to complete. Participants performed a 5-minute to 10-minute warm-up at 60 revolutions/minute on a stationary bicycle. A general flexibility routine involving the trunk and the

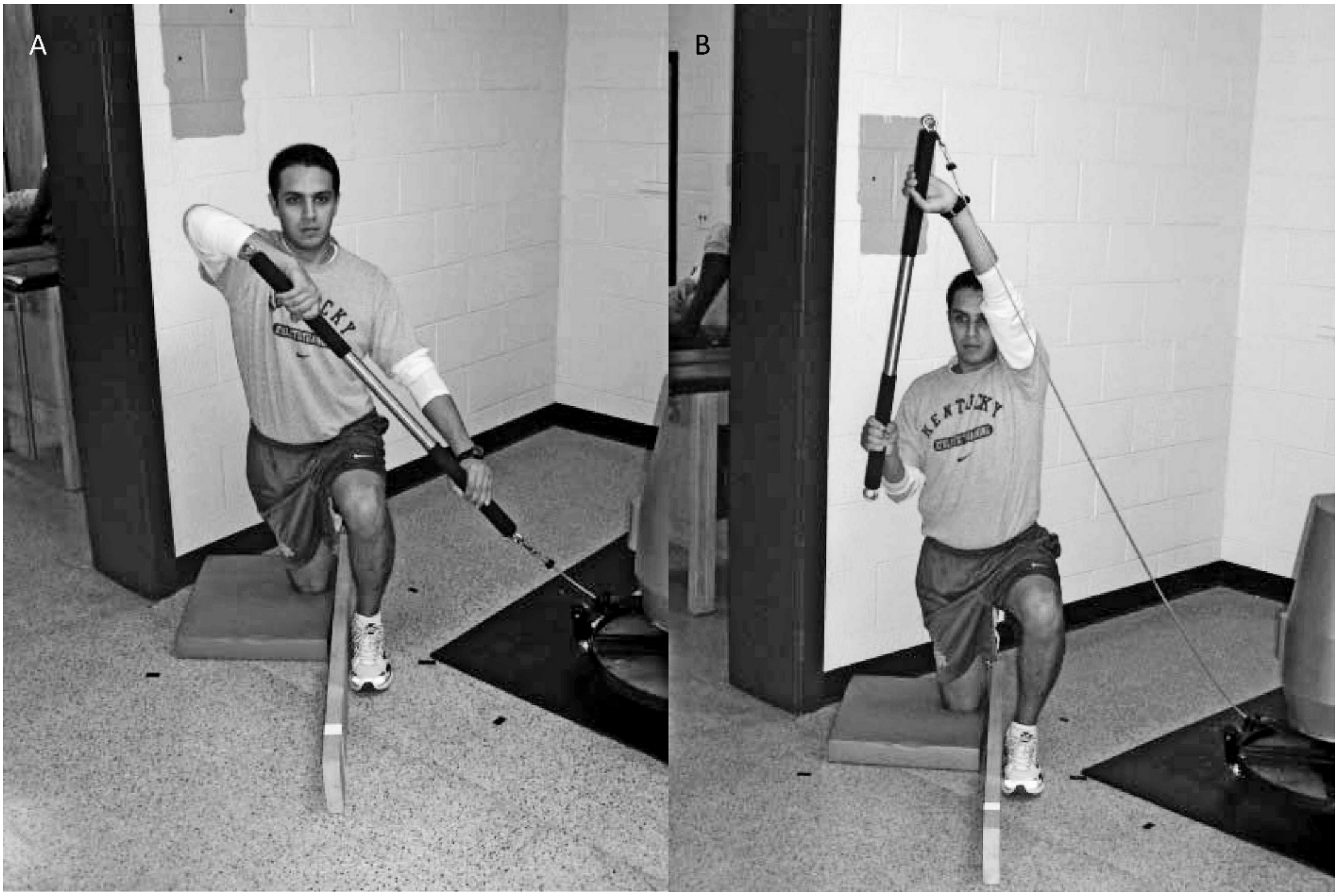


**Figure 2. Lift test, right. The diagonal lifting motion moves across the torso in an upward direction from left to right. A, Beginning position. B, Ending position.**

upper and lower extremities was used to prepare the participants for rotational and stability forces. All testing sessions were initiated with the power tests, followed by a 5-minute rest period and then the endurance tests.[28] The order of power tests (chop left, chop right, lift left, lift right) and endurance tests (Biering-Sørensen, side-plank left, side-plank right) were counterbalanced using a Latin-square design. All participants were instructed to produce a maximal effort for each test. Three separate testing sessions were performed at least 7 days apart.

## Power Testing Protocol

Before all testing sessions, participants viewed a video demonstrating the proper chop and lift techniques. Each participant practiced the maneuvers while viewing the video and received feedback to ensure proper technique. During the first testing session, one investigator (T.G.P.) placed the participants into a half-kneeling position and instructed them for approximately 5 to 10 minutes on maintaining an erect trunk while performing the tests. Proper test position was reviewed before each testing session. The half-kneeling position was standardized to a 90° hip-flexion and knee-flexion position with a 2 × 6 × 60-in (5.08 × 15.24 × 152.4-cm) wooden plank placed between the legs. The knee and foot maintained flush contact with the board to keep the base of support narrow and to maintain a consistent challenge to the trunk stabilizers.[29] A standard 46 × 43 × 13-$cm^3$ block of medium-density foam pad (Airex AG, Sins, Switzerland) was used to support the weight-bearing knee for the comfort of the participant. The PrimusRS dynamometer (BTE Technologies, Inc, Hanover, MA) was used to perform the chop and lift tests. The sport package for the PrimusRS is equipped with a 1.9-lb (0.86-kg), 36-in (91.44-cm) metal dowel rod that can be secured to a 9-ft (2.75-m), 3-dimensional cable motion system (Figure 3A). Participants were instructed to look at a fixed point while maintaining a stable torso and a half-kneeling position during all chop and lift repetitions. Initially, participants received instruction on maintaining proper form and test performance for approximately 5 to 10 practice repetitions with a submaximal weight. Based on pilot data, initial testing resistance was standardized to approximately 12% and 15% of the individual's body mass for the lift and chop tests, respectively. The weight of the dowel rod (1.9 lb [0.86 kg]) was calculated as part of the test resistance provided by the PrimusRS system. Resistance was increased by 3 lb (1.35 kg) for the lift and 5 lb (2.25 kg) for the chop after a successful 1RM. Inability to produce an equal or greater peak power output value from the previous test trial resulted in a reduction in resistance by 1 lb (0.45 kg) for the lift and by 3 lb (1.35 kg) for the chop. Further adjustments were made to the resistance in 1-lb (0.45-kg) increments (increase or decrease) until maximal peak muscular power was achieved. Participants performed

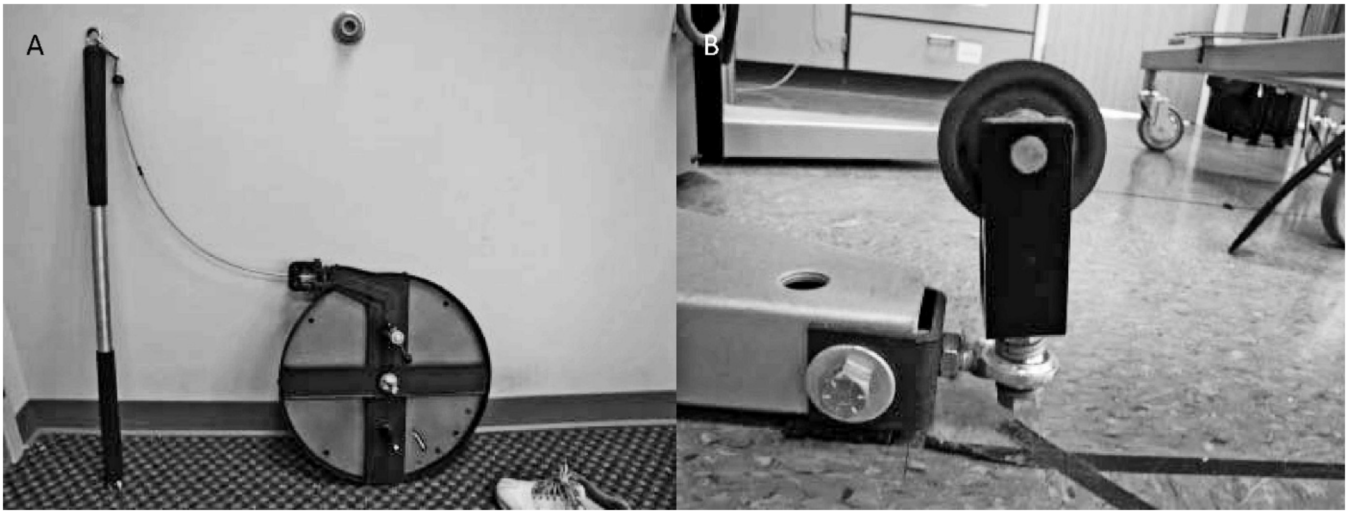


**Figure 3. The PrimusRS 3-dimensional motion system (BTE Technologies, Inc, Hanover, MD) consists of a rotating head attaching a 9-ft (2.75-m) cable through a grounded pulley to a 36-in (91.44-cm), 1.9-lb (0.86-kg) dowel rod to allow for linear displacement. A, BTE PrimusRS 3-dimensional motion system. B, Grounded pulley.**

a series of 1RM efforts for each test with a minimum rest period of 30 seconds between attempts. Peak muscular power (watts) and the number of repetitions (mean, 4 repetitions; range, 2–7 repetitions) used to achieve this level were recorded for each of the 4 power tests for each participant.

**Chop Test.** In a half-kneeling stance, the hand on the same side of the kneeling limb was placed at the bottom of the metal dowel rod, and the opposite hand was placed in an overhead position at the top of the dowel rod (Figure 1). The metal dowel rod was pulled or pushed diagonally downward across the torso by both arms in a chopping motion.[17] The test was called *right* when the dowel rod was chopped from an overhead position toward the kneeling right limb and was called *left* when the chop was toward the kneeling left limb.

**Lift Test.** From a half-kneeling stance, the hand on the kneeling side was placed at the bottom of the metal dowel rod at the level of the hip, the opposite elbow was flexed, and the opposite hand was placed at chest height (Figure 2). The metal cable traveled through a grounded pulley during the lift tests, which allowed for redirection of the linear displacement from the floor (Figure 3B). The metal dowel rod was pulled or pushed diagonally across the torso in an upward lifting motion.[17] The test was called *right* when the metal dowel rod was lifted across the trunk from a downward position toward the right side of the body in a more upward position. It was called *left* when the dowel rod was lifted across the torso toward the left side of the body and away from the supported right limb.[4]

The PrimusRS system calculated isotonic peak muscular power outputs in watts using the traditional equation of dividing work by time, with work equaling force $\times$ distance. Power was a product of force (Newtons) placed on the cable by the dynamometer multiplied by the distance (meters) that the cable was displaced divided by time (seconds). Instantaneous power was determined at 5-millisecond intervals based on the sampling frequency of 200 Hz. Peak muscular power was the highest power output recorded during a single repetition of the chop or lift test.

## Endurance Testing Protocol

Participants were shown a photograph of the endurance tests and were able to practice the test position 1 to 2 times for approximately 5 seconds before testing. Participants focused on a fixed point while holding the static posture for as many seconds as possible. Endurance tests were terminated if the neutral position was disrupted because of fatigue or pain or because a 5° deviation occurred and could not be corrected after oral encouragement. The examiner (T.G.P.) provided oral feedback to correct observed position faults but did not provide motivation or encouragement. When a participant was unable to comply with the desired position, the test was terminated, and the time was recorded. Hold times were not reported after each test session to blind participants to the results until all 3 data collections were completed. A 1:5 work-to-rest ratio was used between endurance measures.[19,28]

**Biering-Sørensen Test.** Participants were positioned prone on a padded treatment table, and their legs were secured with inelastic straps at the ankles, knees, and hips below the anterosuperior iliac spine. With their arms across their chests, participants were instructed to extend and hold an erect neutral position for as long as possible. No participant exceeded 3 minutes, 54 seconds (Figure 4).

**Side-Plank Test.** Participants were positioned side lying on a padded table with the body straight. Each participant was instructed to suspend his or her torso and hips on a flexed elbow and the lateral surface of the foot nearest the table with the legs fully extended. The supporting shoulder was abducted to approximately 80° to 85° in the frontal plane with 90° of elbow flexion. The opposite arm was placed across the chest with the hand on the shoulder. Side planks were performed for the left and right sides. We instructed the participants to hold the test position for a long as possible. No participant exceeded 2 minutes, 56 seconds (Figure 5).

## Statistical Analysis

We used an interday repeated-measures study design. The independent variables were the chop and lift tests for

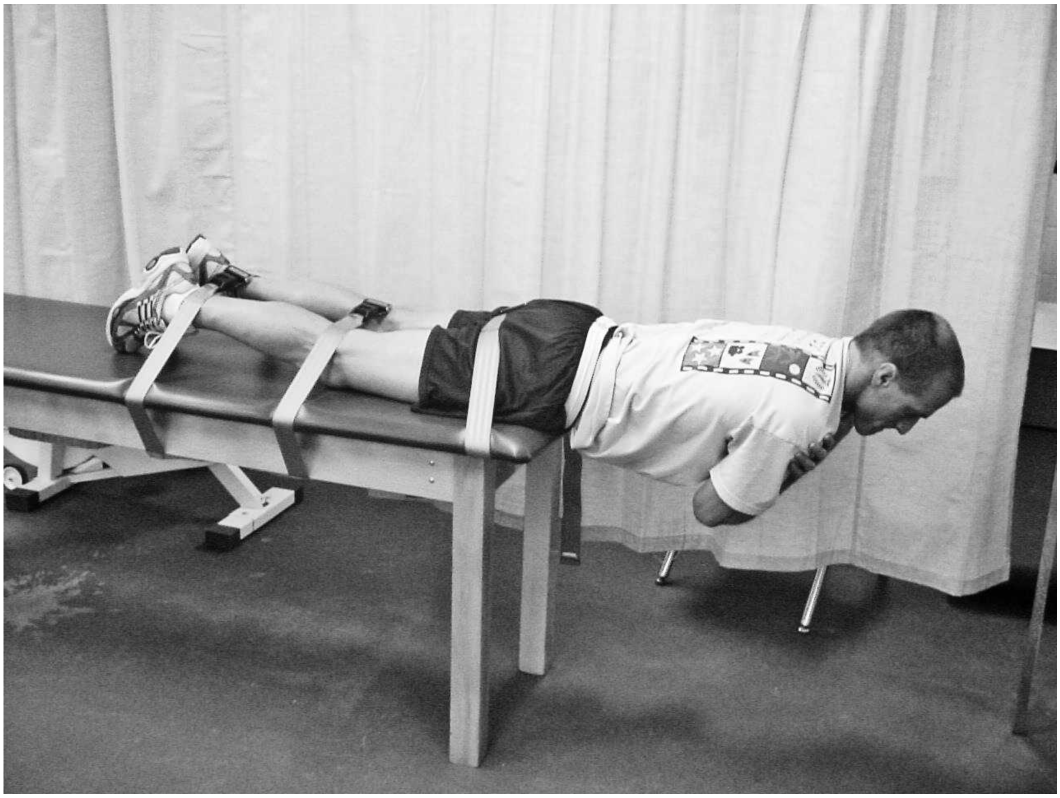

**Figure 4. Biering-Sørensen isometric endurance test. Participants were instructed to stabilize and maintain an erect torso with their legs secured to a treatment table.**

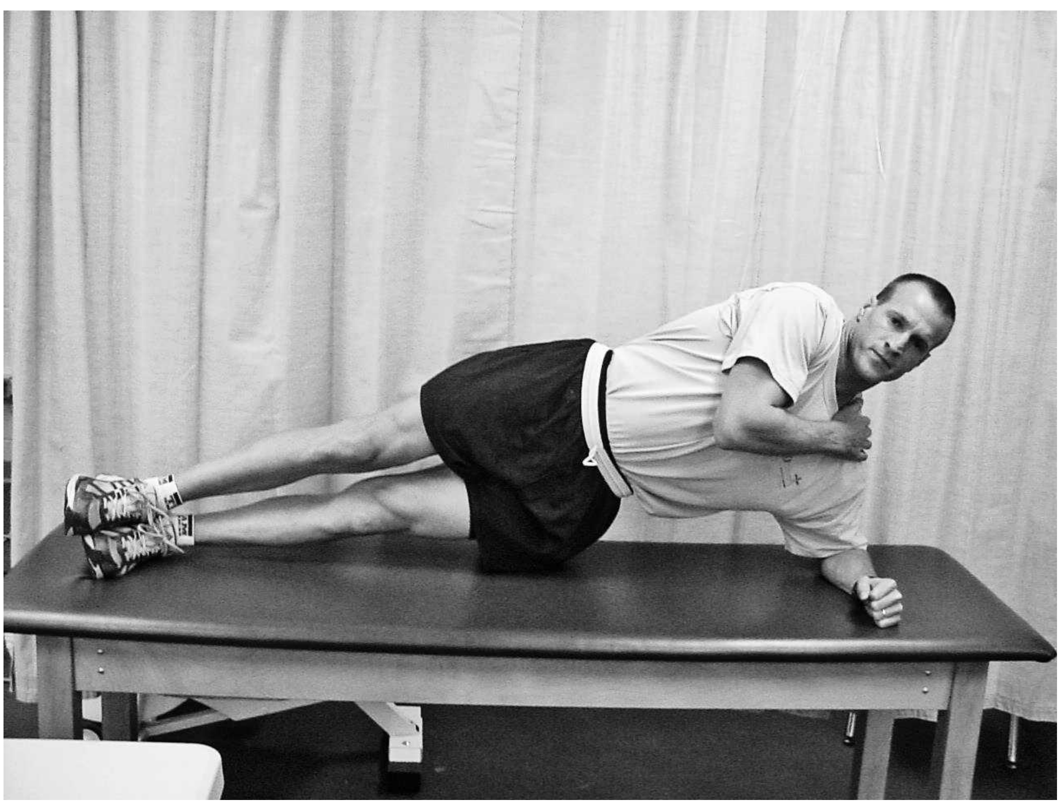

**Figure 5. Side-plank isometric endurance test performed to the left side. The erect torso and lumbopelvic area were supported over the elbow and the feet. During performance, a visual target was provided to help the participant maintain focus and balance.**

**Table 1. Interday Reliability of Chop and Lift Power Tests**

| Test | Day 1 to Day 2[a] Intraclass Correlation Coefficient | 95% Confidence Interval Lower Limit | 95% Confidence Interval Upper Limit | Day 2 to Day 3[b] Intraclass Correlation Coefficient | 95% Confidence Interval Lower Limit | 95% Confidence Interval Upper Limit | Standard Error of Measurement, W[c] | Minimal Detectable Change, W[d] |
|---|---|---|---|---|---|---|---|---|
| Chop left | 0.93 | 0.91 | 0.98 | 0.97 | 0.93 | 0.99 | 34 | 48 |
| Chop right | 0.87 | 0.68 | 0.95 | 0.98 | 0.95 | 0.99 | 28 | 39 |
| Lift left | 0.96 | 0.92 | 0.98 | 0.83 | 0.60 | 0.93 | 52 | 73 |
| Lift right | 0.91 | 0.79 | 0.96 | 0.86 | 0.67 | 0.94 | 41 | 48 |

[a] Indicates tests between day 1 and day 2.
[b] Indicates tests between day 2 and day 3.
[c] Calculated using the pooled SD.[30]
[d] Calculated using standard error of measurement values from all testing days.[26]

the left and right sides, the Biering-Sørensen test, and the side-plank tests for the left and right sides. The dependent variables of interest were peak muscular power output (watts) and seconds during the endurance tests (Biering-Sørensen, side-plank left, side-plank right). A 1-way, random-effects, repeated-measures analysis was used to determine intraclass correlation coefficients for each dependent variable between test days 1 and 2 and again between days 2 and 3. The precision of these tests was determined with standard error of measurement, and the responsiveness of meaningful change between 2 test days was estimated using the minimal detectable change (MDC).[30] A bivariate Pearson product moment correlation (2 tailed) was performed on the day 2 test values to determine the degree of relationship between the 4 power tests and the 3 endurance tests. Day 3 was selected for the precision and correlation calculations to account for the observed learning effect for the endurance tests across days. All statistical analyses were performed using SPSS (version 17.0; SPSS Inc, Chicago, IL).

## RESULTS

Peak muscular power tests exhibited moderate to high reliability (range, 0.83–0.98) (Table 1). Peak muscular power (watts) and endurance test outputs (seconds) for test days 1, 2, and 3 are reported in Table 2. Repeatability among all the endurance tests had high reliability (range, 0.80–0.98) (Table 3). Correlations between the Biering-Sørensen and the power tests were low (range, −0.135 to 0.017) (Table 4). We observed high correlations between power tests (*r* range, 0.768–0.975) and moderate to high correlations among all endurance tests (*r* range, 0.568–0.972). The side-plank endurance tests were moderately correlated with the chop test (*r* range, 0.528–0.590) and to a lesser degree with the lift test (*r* range, 0.359–0.467) (Table 4).

## DISCUSSION

We hypothesized that the peak muscular power output measures from the chop and lift tests would be reliable between days. Our results supported this hypothesis with relatively high reliability across all 3 test days. We also hypothesized that the correlation between the power and endurance tests would be low. The results of the Biering-Sørensen test supported this hypothesis; however, the side-plank tests generated moderate to low correlations with the power outputs from the chop and the lift tests. Our results indicated that the diagonal chop and lift tests are novel quantitative assessments of functional tasks compared with the static linear measures.

The peak muscular power data generated by the chop and lift tests were difficult to compare with data from other studies because these were novel tests. However, the power outputs appeared reasonable when compared with previously reported peak and average power values (range, 200–800 W) of anaerobic power tests (Wingate).[31] The muscular power from the chop (mean, 373 ± 44 W; range, 43–890 W) and the lift (mean, 216 ± 34 W; range, 25–435 W) tests was based on 1RM efforts. Tests such as the Wingate test are derived from short-burst anaerobic energy with multiple repetitions. Upper body ergometer Wingate tests for the general population average approximately 300 to 400 W, whereas lower body Wingate tests average 500 to 800 W.[31] A degree of face validity is evident because our anaerobic power outputs were relatively comparable with those previously reported. The power outputs were reasonable values but differed slightly because the 1RM peak muscular power outputs were attained from an "immediate" anaerobic energy source, whereas the Wingate test values typically are considered short-term anaerobic power efforts, usually lasting 6 to 30 seconds.[32]

Power training and explosive activities have been reported to improve function of daily tasks and promote

**Table 2. Peak Muscular Power and Endurance Test Outputs**

| Test | Day 1 Mean ± SD | Day 1 Range | Day 2 Mean ± SD | Day 2 Range | Day 3 Mean ± SD | Day 3 Range |
|---|---|---|---|---|---|---|
| Chop left, W | 348 ± 194 | 54–890 | 375 ± 199 | 53–800 | 387 ± 198 | 70–786 |
| Chop right, W | 346 ± 184 | 43–761 | 387 ± 196 | 56–778 | 395 ± 212 | 66–835 |
| Lift left, W | 195 ± 124 | 41–435 | 191 ± 116 | 37–422 | 223 ± 140 | 46–470 |
| Lift right, W | 181 ± 106 | 25–425 | 196 ± 106 | 31–428 | 215 ± 112 | 45–437 |
| Biering-Sørensen, s | 115 ± 49 | 44–225 | 129 ± 54 | 63–222 | 130 ± 54 | 63–234 |
| Side-plank left, s | 69 ± 36 | 23–166 | 74 ± 36 | 37–154 | 76 ± 39 | 24–169 |
| Side-plank right, s | 64 ± 40 | 16–156 | 71 ± 43 | 16–174 | 75 ± 41 | 22–176 |

**Table 3. Interday Reliability of Muscular Endurance Tests**

| Test | Day 1 to Day 2[a] Intraclass Correlation Coefficient | Day 1 to Day 2[a] 95% Confidence Interval Lower Limit | Day 1 to Day 2[a] 95% Confidence Interval Upper Limit | Day 2 to Day 3[b] Intraclass Correlation Coefficient | Day 2 to Day 3[b] 95% Confidence Interval Lower Limit | Day 2 to Day 3[b] 95% Confidence Interval Upper Limit | Standard Error of Measurement, s[c,d] | Minimal Detectable Change, s[c,e] |
|---|---|---|---|---|---|---|---|---|
| Biering-Sørensen | 0.80 | 0.65 | 0.97 | 0.98 | 0.95 | 0.99 | 7 | 10 |
| Side-plank left | 0.89 | 0.81 | 0.97 | 0.96 | 0.91 | 0.98 | 7 | 10 |
| Side-plank right | 0.91 | 0.80 | 0.97 | 0.98 | 0.95 | 0.99 | 6 | 8 |

[a] Indicates tests between day 1 and day 2.
[b] Indicates tests between day 2 and day 3.
[c] Time in seconds is the average amount of seconds for each endurance test for all sessions.
[d] Calculated using the pooled SD.[30]
[e] Calculated using standard error of measurement values from all testing days.[26]

muscle hypertrophy at a more efficient rate than does slow-velocity resistance training.[33–37] Activities that produce higher force at high velocities at the distal segments (kicking, throwing, landing) depend on moments created in the proximal segments.[24,25,38] Therefore, it is reasonable to combine diagonal patterns using the extremities with a 1RM protocol to determine the power capacity of the upper extremity and trunk functioning together. Several authors[14,22,25,29,39,40] have recognized the importance of active trunk control during power movements but have not fully explored the use of peak muscular power and trunk control. These results indicate that the dynamic power test might be a reliable method with which to further explore these systems and how they change in response to injury or training.

Nesser et al[41] and Nesser and Lee[42] studied the correlation between power performance measures and tests that challenge dynamic trunk activity. In both studies, the authors reported very low to moderate correlations ($r$ range, 0.099–0.6) between trunk muscular measures (planks, trunk flexion-extension repetitions) and power performance measures (20-yd [18.3-m] and 40-yd [36.6-m] sprints, vertical jump) among football players and female soccer players.[41,42] They concluded the assessment tests used had very little to do with athletic performance measures in these sports and the assessment techniques used possibly were not specific enough to evaluate athletic performance.[41,42] The measures used in these studies were primarily static linear tests and static muscular-endurance tests and not explosive anaerobic tasks commonly associated with sport performance. The low to moderate correlations ($r$ range, 0.099–0.6) between the static/linear tests and sport performance measures were similar to the correlations between the power and endurance assessment tests used in our study ($r$ range, −0.008 to 0.590). Our results offer further evidence that trunk stability during dynamic arm movements might function along a muscular performance continuum (power–strength–endurance), as suggested by McGill et al.[22] The moderate correlations between the power and side-plank tests ($r$ range, 0.359–0.590) revealed that approximately 33% of the variance is explained by the static measures. The fact that approximately 66% of the variance is unexplained between these measures indicates that the chop and lift protocol might provide another method with which to further investigate activities of daily living and sport by requiring the distal extremities to exert a maximal effort on a stable proximal base.

Recently, McGill et al[22] hypothesized that the hip and trunk stabilizers can develop sport-specific anaerobic capabilities that assist in the performance of explosive tasks. Some authors[22,23,29,40,43,44] have suggested these muscular characteristics are directly related to sport specificity, the bioenergetics of an individual, and the range of motion needed to successfully complete a given task. McGill et al[22] evaluated electromyography of the lumbopelvic-trunk musculature along a stability continuum and concluded that different levels of trunk muscular activation and stiffness are required for different activities and should be trained according to the mobility and stability needs of a specific task. In addition, traditional linear and static measures commonly used for patients with low back conditions or lower levels of trunk stabilization likely are less appropriate for monitoring trunk control at higher levels of activity.[3,45] Therefore, clinicians should consider assessing dynamic trunk control on a continuum that progresses from low to high levels of muscular activity. The chop and lift tests might be good alternative tests when

**Table 4. Bivariate Pearson Product Moment Correlation Coefficients (*P* Values) for Day 3 of Testing**

| Test | Endurance Test: Biering-Sørensen | Endurance Test: Side-Plank Left | Endurance Test: Side-Plank Right | Power Test: Chop Left | Power Test: Chop Right | Power Test: Lift Left | Power Test: Lift Right |
|---|---|---|---|---|---|---|---|
| Biering-Sørensen | 1[a] | 0.615 (.007[b]) | 0.568 (.01[b]) | −0.027 (.92) | 0.017 (.95) | −0.008 (.97) | −0.135 (.59) |
| Side-plank left | | 1[a] | 0.972 (<.001[b]) | 0.528 (.02[b]) | 0.547 (.03[b]) | 0.451 (.06) | 0.367 (.13) |
| Side-plank right | | | 1[a] | 0.584 (.01[b]) | 0.590 (.01[b]) | 0.467 (.05) | 0.359 (.14) |
| Chop left | | | | 1[a] | 0.975 (<.001[b]) | 0.768 (<.001[b]) | 0.860 (<.001[b]) |
| Chop right | | | | | 1[a] | 0.783 (<.001[b]) | 0.857 (<.001[b]) |
| Lift left | | | | | | 1[a] | 0.769 (<.001[b]) |
| Lift right | | | | | | | 1[a] |

[a] Indicates perfect correlation.
[b] Indicates difference ($P < .05$).

assessing movements involving the trunk. The combination of ballistic arm movements and the narrow base of support in the half-kneeling stance creates a different state from that associated with the static plank test, which offers an alternative challenge to the proximal stabilizers.[23,29] Sport-specific training and assessments have been implemented for decades; these tests might provide another method to evaluate active extremity and trunk function. Further research is needed to investigate the performance capabilities as they pertain to specific tasks that require muscular power rather than muscular endurance.

Muscular endurance characteristics of the hip and trunk stabilizers traditionally have been recognized as primary contributors in maintaining a stable lumbopelvic area.[6,8,11] As a result, the Biering-Sørensen and side-plank tests have become 2 of the most common clinical tests used to assess the isometric endurance capabilities of the hip and trunk musculature to identify individuals with potential dysfunction.[18,19,46] Therefore, we investigated the relationship between the traditional measures and a novel test with the expectation that the correlation between them would be low, per our hypothesis. The moderate correlation (*r* range, 0.359–0.590; *P* range, .01–.14) between the side-plank tests and the power maneuvers indicated that both tests challenge the lateral stabilizers (oblique musculature, transverse abdominus) but conceivably through the use of different muscle bioenergetics.[22,46] Although not quantified in our study, the correlations between the chop test and the side-plank tests are likely due to similarities in the muscular activation of the lateral trunk and abdominal obliques necessary to complete these movements.[47] The low to moderate correlations between the different assessment protocols support the divergent validity of the power test outputs. Both the power and endurance assessment protocols appear to be measuring different characteristics, perhaps on a performance continuum.[22]

Diagonal movements, such as those used in the chop and lift tests, are likely to promote sequential muscle activation on multiple planes between the proximal and distal body segments. The muscular endurance tests tend to isolate a select group of muscles while functioning on a single plane.[1,16,17,20,25] The erector spine, gluteal, or hamstrings muscles have been reported[20] to be active predominantly during a supine-plank position and Biering-Sørensen prone position. The anterior musculatures of the torso and pelvis are active predominately during a prone-plank position, whereas the lateral trunk stabilizers are isolated with the side-plank positions.[20,47–49] The trunk stabilizers seldomly are isolated in this manner[22]; rather, they function collectively on multiple planes to provide different degrees of stability and mobility.[50–52] As such, researchers[39,48,53–55] have reported that static and 1-dimensional muscular endurance tests are poorly correlated with tasks associated with daily function and sport. In part, this is likely due to the limited multidimensional and diagonal movements commonly used in sport. McGill et al[22] identified the potential importance of incorporating diagonal movement patterns because greater electromyographic peak torque activation among a variety of trunk musculature was evident when compared with linear stability tasks. Furthermore, the use of diagonal movement patterns has been reported[16] to promote a balance between agonist and antagonist muscle activation of multiple muscle groups. Thus, diagonal movement patterns of the extremities should be considered because they promote a comprehensive integration of active trunk stability on multiple planes. The results of our study provide a foundation for further investigations involving diagonal movements and functional tasks.

To have clinical meaningfulness, a new clinical test needs to demonstrate high reliability, validity, and responsiveness to change.[30] The primary purpose of our study was to evaluate interday reliability of peak muscular output measures using diagonal chop and lift tests; the reliability was found to be good to excellent (intraclass correlation coefficient range, 0.83–0.98). However, a gradual increase in the peak power outputs from day 1 to day 3 for each testing session indicated that learning might have been occurring (Table 2). In previous studies,[18,19] investigators have identified a learning effect between testing sessions for muscular endurance tests involving the trunk and pelvic musculature. Based on our study and previous reports, we suggest that a familiarization period be included. At least 1 day of testing or training is recommended to ensure that measurable changes are true and are not due to learning.[48]

We did not specifically evaluate responsiveness because it would have required either an intervention or 2 separate populations. However, the calculation of standard error of measurement and MDC describes the potential change that would be needed to determine a true change in performance (Tables 1 and 2). The MDC values represent the minimal amount of change necessary to determine a true change has occurred beyond the measurement error. The average MDCs for the 4 power tests were about 20% of their respective mean values. An approximate increase in performance of 20% would represent a meaningful clinical change for the power tests. This percentage is similar to that found with traditional static measures within a general population.[18] This percentage of change seems reasonable because other measures, such as numeric pain rating scales, require a 2 out of 10 change to indicate a meaningful change.[56]

The initial test resistance of 12% and 15% body mass for the lift and chop tests, respectively, appears to be a relatively good recommendation when testing the general population for 1RM. The average number of repetitions needed to reach maximal peak power outputs was 3 for the lift tests and 4 for the chop tests. Testing resistance that is closer to an individual's 1RM makes the testing process more efficient.[57] Although not different, a trend of more trials for the chop test was evident among participants scoring "high" (>7) on the Tegner activity scale. Our results indicated that individuals with a higher activity level or those competing in sport might benefit from using a higher starting resistance, such as 20% to 25% of the total body mass, especially with the chop test.

## Limitations

Although the values gained from the chop and lift tests were reliable and attainable in approximately 30 minutes (mean = 26 ± 3.9 minutes), the test techniques did have some limitations. The diagonal patterns required the participant to create forceful movements of the upper body while maintaining a stable proximal base from a half-kneeling position. This required individuals to have adequate upper body strength and coordination to perform these movements. It is impossible to not consider the contributions made by the upper extremity to the testing procedure and, therefore, the contribution to the peak power generated. This test does not isolate the specific trunk musculature but evaluates contributions of dynamic trunk control while an individual performs a functional task with the lower and upper extremity as a single forceful unit. The lift motion is a slightly awkward movement; compared with the chop test, it requires more time to practice, to instruct the participant in use, and to complete testing. Improvements in the testing protocol might be needed to refine the overall efficiency of the assessment techniques.

## CONCLUSIONS

The chop and lift tests performed on the PrimusRS dynamometer provided repeatable measures of power output from week to week in the general population. This novel test appeared to measure a different construct than muscular endurance because correlations with the Biering-Sørensen and side-plank tests were low to moderate. The frequent use of power movements on multiple planes in athletics and in daily tasks requires clinicians and researchers to identify testing techniques that evaluate these effects. We believe the chop and lift 1RM protocol has good potential to serve this purpose because it appears to measure functional tasks that require dynamic trunk control. Further testing and modification of this protocol might provide additional evidence to support the potential roles that muscular power might play during specific activities.

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# Scapular-Muscle Performance: Two Training Programs in Adolescent Swimmers

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***Context:*** Swimming requires well-balanced scapular-muscle performance. An additional strength-training program for the shoulders is pursued by swimmers, but whether these muscle-training programs need to be generic or specific for endurance or strength is unknown.

***Objective:*** To evaluate isokinetic scapular-muscle performance in a population of adolescent swimmers and to compare the results of training programs designed for strength or muscle endurance.

***Design:*** Controlled laboratory study.

***Setting:*** University human research laboratory.

***Patients or Other Participants:*** Eighteen adolescent swimmers.

***Intervention(s):*** Each participant pursued a 12-week scapular-training program designed to improve either muscle strength or muscle endurance.

***Main Outcome Measure(s):*** Bilateral peak force, fatigue index, and protraction/retraction strength ratios before and after the scapular-training program.

***Results:*** Scapular protraction/retraction ratios were slightly higher than 1 (dominant side = 1.08, nondominant side = 1.25, $P = .006$). Side-to-side differences in retraction strength were apparent both before and after the training program ($P = .03$ and $P = .05$, respectively). After the training program, maximal protraction ($P < .05$) and retraction ($P < .01$) strength improved on the nondominant side. Peak force and fatigue index were not different between the training groups. The fatigue indexes for protraction on both sides ($P < .05$) and retraction on the nondominant side ($P = .009$) were higher after the training program.

***Conclusions:*** We describe the scapular-muscle characteristics of a group of adolescent swimmers. Both muscle-strength and muscle-endurance programs improved absolute muscle strength. Neither of the strength programs had a positive effect on scapular-muscle endurance. Our results may be valuable for coaches and physiotherapists when they are designing exercise programs for swimmers.

***Key Words:*** upper extremity, strength training, endurance training, athletes

**Key Points**

- We describe sport-specific adaptations regarding scapular-muscle performance in adolescent swimmers. Increased protraction strength and side-to-side differences were observed.
- In these athletes, both strength-training and muscle-endurance programs improved scapular-muscle strength, but neither program improved scapular-muscle endurance.
- Addressing muscle imbalances and asymmetry may be important to preventing injury in adolescent swimmers.

Swimming is a demanding sport, especially with respect to the shoulder joint. Shoulder injuries frequently occur in swimming athletes: 47% to 80% of all competitive swimmers reported shoulder injuries during their sport careers.[1–3] Swimming requires many sequential repetitive movements, with little opportunity for rest. An elite swimmer performs approximately 2500 shoulder revolutions during each training session. Consequently, sufficient upper limb muscle endurance and strength are necessary in these athletes.

The scapular muscles have an important function in swimming.[4–6] Electromyographic stroke analysis shows that the serratus anterior muscle has the leading function,[4] being continuously active throughout the stroke and positioning the scapula for hand entry, hand exit, and pulling the body over the arm. As a result, the serratus anterior may be susceptible to fatigue. An appropriate upward rotation of the scapula is necessary to avoid impingement during the swimming stroke. Considering the cooperation between the serratus anterior and lower trapezius muscles in scapular upward rotation,[7] the lower trapezius is also of importance in swimming.[5,6]

The function of the scapular muscles in swimming has already been examined by several authors.[5,6] In 2004, Su et al[6] compared isometric strength values of the scapular muscles in swimmers before and after a single swim session. Serratus anterior and upper trapezius strength decreased by 14% and 13%, respectively. Fatigue of the scapular muscles may influence other factors, such as muscle activity and kinematics. A few researchers[8,9] examined the effect of serratus anterior fatigue on muscle-activation timing and scapular kinematics. After a fatigue protocol for the serratus anterior, muscle activation was greater in the upper trapezius, which can compensate for serratus anterior fatigue. The scapular kinematics after serratus anterior fatigue were characterized by decreased posterior tilting and increased internal rotation. Alterations in both muscle activation and scapular kinematics may contribute to shoulder injuries, including subacromial impingement syndrome and glenohumeral joint instability.[10–12] In patients with subacromial impingement, decreased serratus anterior activity and increased anterior tipping and internal rotation were found.[12]

Because of the increased need for muscle endurance and the considerable risk for shoulder injuries, swimmers may benefit from a specific shoulder-training program. However, evidence about the most effective way of training (for instance, muscle-strength versus muscle-endurance training) is lacking. In the literature, strength programs have focused primarily on the glenohumeral muscles and on maximal strength to improve sport performance.[13–17] One group[18] examined the effect of a functional strength program, with selected exercises for the rotator cuff and serratus anterior, on the incidence of shoulder pain. For the serratus anterior only, an endurance program (3 sets until exhaustion) was followed; for the other muscles, 3 sets of 10 repetitions were completed. However, in the strength evaluation, only maximal strength was measured. An endurance-specific measurement, such as the fatigue index (FI), was not investigated. Thus, no conclusions about muscle endurance could be made. With respect to the available literature on strength training in swimmers, whether programs should focus on maximal strength or on muscle endurance is unknown.

We had several goals for our study. First, we evaluated the isokinetic muscle performance of the scapular muscles in adolescent swimmers by assessing peak force and the FI during an isokinetic protraction-retraction protocol. Second, we compared muscle strength and muscle endurance before and after a strength- or endurance-training program in order to determine whether shoulder muscle-training programs in swimmers need to be specific for muscle strength or endurance. Third, we measured side-to-side differences in strength before and after the training program. To our knowledge, this investigation has never been performed before in adolescent swimmers.

## METHODS

### Participants

A total of 18 adolescent swimmers (11 females, 7 males) participated in our study. All athletes were members of the same swimming club and had 4 to 6 training sessions every week with a mean session duration of 2 hours. The age of participants was 14.7 ± 1.3 years; participant height was 165.2 ± 8.3 cm, and mass was 50.06 ± 9.13 kg. Two swimmers were left handed; the others were right handed. All athletes breathed on both sides while swimming. Exclusion criteria were cervical or thoracic conditions, previous shoulder surgery, or shoulder pain that interfered with swim training. None of the swimmers experienced any shoulder pain during the 12-week test period. Before participating in this study, the swimmers and their parents signed informed consent documents. This study was approved by the ethical committee of Ghent University.

### Design

This study was a 2-group, randomized design with repeated measures. Between the 2 strength and endurance measurements, the volunteers followed a scapular-training schedule of 3 times per week for 12 weeks. The training program was completed before the athletes started swim training each day. All athletes participated in their normal swim practices and races.

### Isokinetic Protraction-Retraction Strength Evaluation

Isokinetic testing is considered the "gold standard" in terms of objectively evaluating an athlete's strength.[19–22] Cools et al[20,21] developed a reliable isokinetic protraction-retraction protocol (intraclass correlation coefficient = 0.88–0.77) in healthy volunteers that was used successfully in athletes.

All isokinetic tests were performed using an isokinetic dynamometer (System 3; Biodex Medical Systems, Inc, Shirley, NY). For isokinetic strength measurement of the scapular muscles, we used the closed chain attachment, which was fixed horizontally to the dynamometer. We followed the same testing procedures and testing positions described by Cools et al.[20,21] Each swimmer performed 2 isokinetic tests on both sides, the first test at a linear speed of 12.2 cm/s (5 repetitions at an angular velocity of 60°/s) and the second test at 36.6 cm/s (40 repetitions at an angular velocity of 180°/s). The resting period between tests was 10 seconds. The first test determined maximal strength, and the second test evaluated muscle endurance. The test started in a maximal retracted position, and participants were instructed to perform maximal protractions followed by retraction movements over the total range of motion. Because movement took place in the horizontal plane, gravity correction was not performed. Before starting data collection, each volunteer performed 5 familiarization trials. During the test, the swimmers were given only verbal encouragement and no visual feedback from the computer screen. The testing sequence was the same for both groups and both sets of measurements.

### Scapular-Training Program

Swimmers were randomly allocated to either the muscle-strength group or the muscle-endurance group. The training program was supervised by a physiotherapist and completed in a gym room near the swimming pool. Exercises were the same for both groups, but training weights and number of repetitions were different so that we could focus on either muscle strength or muscle endurance. Each session consisted of 4 exercises, the first 2 of which were designed to reinforce the serratus anterior muscle and remaining 2 of which were designed for the entire trapezius muscle.[23–25] The schedule was designed to train both muscle groups alternately and was the same for both groups and sessions. We selected the exercises based on previous experimental studies.[23–26] If possible, exercises were performed in the lying position rather than in the standing or sitting position because the supine and prone positions are more sport specific for swimmers. The first exercise (Figure 1) was a variant of the dynamic hug movement,[23] which can be described as horizontal flexion of the humerus, starting at 60° of elevation. The swimmer crossed his or her hands while holding an elastic exercise band. Next, the swimmer performed scapular protraction by moving the hands away from each other. Different-colored exercise bands were used to determine the most suitable amount of resistance. In the second exercise (Figure 2), the swimmer performed an elbow push-up.[24] With both elbows flexed to 90° and upper extremity weight supported by the elbows, full protraction was accomplished. This exercise is a variant of the normal push-up exercise described by Ludewig et al.[24] The exercise was performed on both feet (muscle-strength group) or both knees (muscle-endurance group). The third exercise (Figure 3) was intended for the lower part of the trapezius muscle.[26] While lying on his or her side, the swimmer performed glenohumeral external rotation with a dumbbell. The last exercise (Figure 4) started in the prone position, with both shoulders abducted to 90° and both elbows flexed to 90°. The swimmers performed bilateral glenohumeral horizontal abduction with scapular retraction using 2 dumbbells. The entire muscle (all 3 parts) is active during this exercise.[25]

We determined the 2 training programs based on the clinical literature.[27,28] The strength group trained at a 10–repetition maximum and performed 3 sets of 10 repetitions, whereas the endurance group trained at a 20–repetition maximum and performed 3 sets of 20 repetitions. Weights were reevaluated and adapted after 6 weeks.

**Figure 1. Dynamic hug movement.**

### Data Analysis

We used Biodex software to determine peak force. In addition, we determined protraction/retraction ratios and the FI. The protraction/retraction ratio, with the protraction value as agonist, was calculated based on peak-force data. From the endurance test (40 repetitions), the FI was calculated for further analyses. The FI (percentage) is a ratio of the difference in output during the first and third portions of the test. Negative values indicate that the output in the last third of the test has increased compared with the first third, and positive values represent a decline in output. Peak force during protraction and retraction at low velocity (12.2 cm/s), the strength ratio, and the FI were the dependent variables.

**Figure 2. Elbow push-up.**

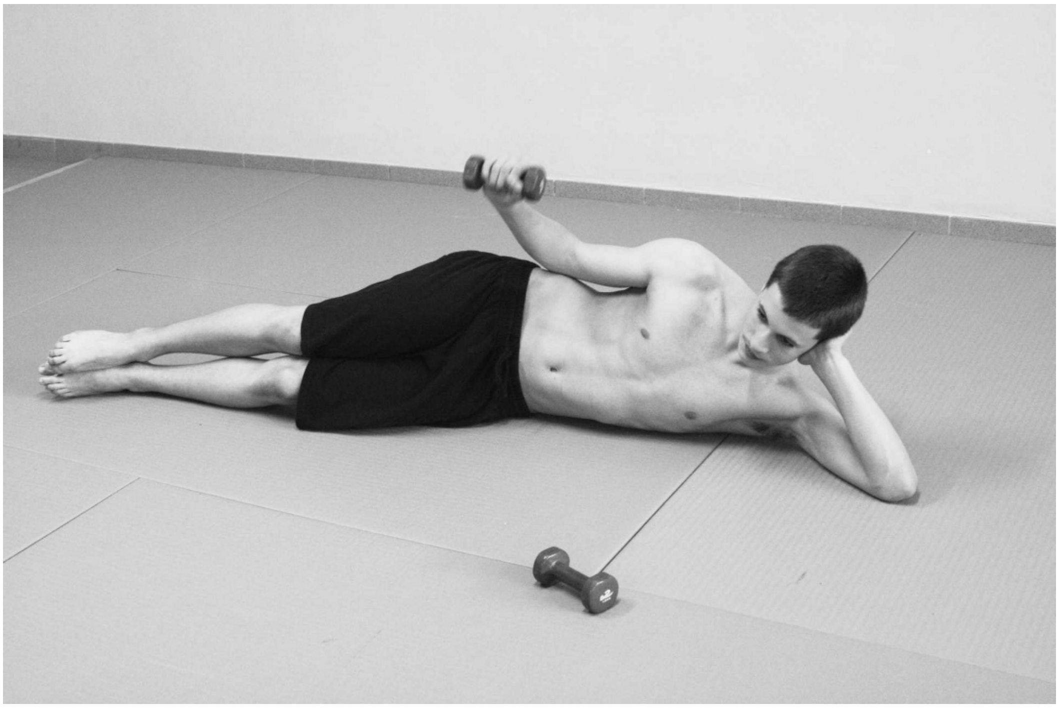

**Figure 3. External glenohumeral rotation.**

We used the Shapiro-Wilcoxon test to control data distribution. In this study, all data were normally distributed with equal variances, so parametric tests were appropriate for further analyses. To analyze anthropometric group differences, an independent $t$ test with $\alpha = .05$ was used. No age, mass, or height differences between groups were noted (all $P$ values $> .05$).

We used a general linear model (GLM) 3-way analysis of variance (ANOVA) with repeated-measures design for statistical analysis. The within-subjects factors were time (pretest, posttest) and side (dominant, nondominant). Group (muscle strength or muscle endurance) was the between-subjects factor. We were interested in interaction effects of time and group, as well as main effects. In the presence of a significant interaction, post hoc Bonferroni $t$ tests were performed. In this study, $\alpha$ was set at .05, and the corrected $\alpha$ was set at .025. All statistical analyses were performed with SPSS (version 15.0; SPSS Inc, Chicago, IL). Power analysis of the strength and endurance values was calculated at 67%.

## RESULTS

### Peak Force

Descriptive data and results from the post hoc Bonferroni adjustments for peak force regarding time (pretraining versus posttraining), group (strength versus muscle endurance), side (dominant versus nondominant), and both movement directions (protraction and retraction) are summarized in Table 1.

The GLM 3-way ANOVA for repeated measures revealed no triple interaction effect for time × side × group for protraction or retraction peak force. Furthermore, we found no 2-way interaction effects for group (time × group or side × group) for protraction or retraction peak force. Finally, none of the between-subjects tests for group were significant for protraction ($P = .60$) or retraction ($P = .50$) peak forces. These results indicate no significant effect of training group.

**Figure 4. Horizontal abduction with scapular retraction.**

Table 1. Peak Force (at 12.2 cm/s) and Post Hoc Results for Protraction and Retraction by Time, Side, and Group (Mean ± SD)

| Motion | Time | Dominant Side: Strength-Training Group (n = 9) | Dominant Side: Muscle-Endurance Group (n = 9) | Dominant Side: Entire Group (N = 18) | Nondominant Side: Strength-Training Group | Nondominant Side: Muscle-Endurance Group | Nondominant Side: Entire Group | *P* Value for Side | *P* Value for Time |
|---|---|---|---|---|---|---|---|---|---|
| Protraction | Pretraining | 206.61 ± 76.09 | 222.18 ± 97.22 | 214.40 ± 85.07 | 200.52 ± 69.07 | 224.01 ± 82.55 | 212.31 ± 74.81 | NA | NA |
| | Posttraining | 234.97 ± 86.31 | 256.31 ± 103.98 | 245.64 ± 93.53 | 225.68 ± 89.07 | 243.34 ± 76.62 | 234,51 ± 81.11 | NA | NA |
| Retraction | Pretraining | 188.36 ± 59.45 | 212.52 ± 101.23 | 200.44 ± 81.48 | 162.58 ± 57.53 | 184.35 ± 76.14 | 137.47 ± 66.42[a] | .030 | <.001[b] |
| | Posttraining | 220.98 ± 64.77 | 222.80 ± 56.61 | 221.89 ± 59.02 | 236.06 ± 59.72 | 262.88 ± 76.47 | 249.47 ± 67.97[a] | .050 | <.001[b] |

Abbreviation: NA, no post hoc test completed because main effects were present.

[a] Significant results.

[b] Significant 2-way interaction for group × side.

For protraction peak force, no 2-way interactions for time × side were noted ($P = .5$ and $P = .8$, respectively). However, a main effect was seen for time on protraction peak force ($P = .037$). Thus, time effects were present equally on both sides and in both groups, and posttraining differences were independent of group and side. Therefore, post hoc analysis on these variables was not performed.

For retraction peak force, a time × side interaction was demonstrated ($P = .005$). Based on post hoc pairwise comparisons with Bonferroni correction for retraction, peak force on the nondominant side was higher posttraining ($P < .001$). No other post hoc pairwise comparisons were significant.

## Protraction/Retraction Ratio

The GLM 3-way ANOVA for repeated measures revealed no triple interaction effect for time × side × group for the protraction/retraction ratio ($P = .7$). Additionally, we found no 2-way interactions for group (time × group or side × group; $P = .8$ and $P = .9$, respectively) or between-subjects main effects for group ($P = .92$).

For the protraction/retraction ratio, the GLM showed a dual time × side interaction ($P = .002$). Using the post hoc test, we noted side-to-side differences at both test moments ($P = .006$ and $P = .024$, respectively). With respect to time differences, the ratio on the nondominant side was lower posttraining ($P < .001$) (Table 2).

## Fatigue Index

No 3-way interaction for time × side × group was revealed by the GLM for the protraction and retraction FIs ($P = .075$ and $P = .90$, respectively). Additionally, no 2-way interactions for group (time × group or side × group) were found for the protraction ($P = .6$ and $P = .075$, respectively) or retraction ($P = .67$ and $P = .57$, respectively) FIs, and no significant between-subjects results for group ($P = .45$ and $P = .51$, respectively) were present (Table 3).

No interaction effects were found for the protraction FI. However, the GLM showed a main effect for time ($P = .003$). The FI was greater posttraining, with increases in all values. A positive FI indicates less muscle endurance. For the retraction FI, a time × side interaction effect was demonstrated ($P = .037$). Using post hoc analysis, we found a training (time) effect on the nondominant side ($P = .009$). The FI was increased on the nondominant side posttraining.

## DISCUSSION

Our purpose was to describe the profile of isokinetic scapular-muscle performance in a population of healthy adolescent competitive swimmers. Additionally, we wanted to verify the effect of 2 types of strength program on scapular-muscle strength in swimmers. Our study provides important information related to scapular-muscle training and adaptations in competitive swimmers.

## Swimmers' Muscle Performance

Based on pretraining results, we offer a scapular-strength profile of adolescent swimmers. Regarding the peak force data, at low velocity our swimmers were stronger in protraction than in retraction movements. This increased protraction strength may be the result of a sport-specific adaptation. Previous researchers[4] showed continuous activity of the serratus anterior muscle. Because of the higher protraction peak force in our swimmers, the protraction/retraction ratio was greater than 1. Among healthy adults not active in overhead sports, the protraction/retraction ratio is approximately 1, meaning that both

Table 2. Protraction/Retraction Ratio (at 12.2 cm/s) and Post Hoc Results by Time, Side, and Group (Mean ± SD)

| Protraction/Retraction Ratio | Dominant Side: Strength-Training Group (n = 9) | Dominant Side: Muscle-Endurance Group (n = 9) | Dominant Side: Entire Group (N = 18) | Nondominant Side: Strength-Training Group | Nondominant Side: Muscle-Endurance Group | Nondominant Side: Entire Group | Post Hoc Results: *P* Value for Side | Post Hoc Results: *P* Value for Time (Nondominant Side) |
|---|---|---|---|---|---|---|---|---|
| Pretraining | 1.09 ± 0.23 | 1.07 ± 0.14 | 1.08 ± 0.19 | 1.23 ± 0.14 | 1.27 ± 0.35 | 1.25 ± 0.26[a] | .006 | NA |
| Posttraining | 1.06 ± 0.28 | 1.09 ± 0.33 | 1.08 ± 0.30 | 0.94 ± 0.28 | 0.92 ± 0.15 | 0.93 ± 0.22[a] | .024 | <.001 |

Abbreviation: NA, no post hoc test completed because main effects were present.

[a] Significant 2-way interaction for group × side.

[b] Significant results ($P < .025$).

Table 3. Fatigue Index and Post Hoc Results for Protraction and Retraction (at 36.6 cm/s) for Side, Group, and Time (Mean ± SD)

| Fatigue Index | Time | Dominant Side: Strength-Training Group (n = 9) | Dominant Side: Muscle-Endurance Group (n = 9) | Dominant Side: Entire Group (N = 18) | Nondominant Side: Strength-Training Group | Nondominant Side: Muscle-Endurance Group | Nondominant Side: Entire Group | P Value for Side | P Value for Time |
|---|---|---|---|---|---|---|---|---|---|
| Protraction | Pretraining | 1.36 ± 29.27 | −14.7 ± 59.51 | −6.67 ± 44.22 | −32.33 ± 43.96 | 3.43 ± 20.19 | −14.45 ± 37.90 | NA | NA |
| | Posttraining | 10.8 ± 17.18 | 15.16 ± 11.75 | 12.98 ± 14.45 | 13.25 ± 20.89 | 15.48 ± 12.50 | 14.37 ± 16.74 | NA | NA |
| Retraction | Pretraining | −3.01 ± 16.17 | 2.12 ± 21.18 | −0.44 ± 18.40 | −23.72 ± 44.36 | −11.45 ± 45.94 | −17.58 ± 4.26[a] | .089 | .009[b] |
| | Posttraining | 4.86 ± 19.99 | 6.36 ± 20.60 | 5.61 ± 19.70 | 10.85 ± 19.82 | 16.75 ± 19.60 | 13.80 ± 1.93[a] | .071 | .009[b] |

Abbreviation: NA, no post hoc test completed because main effects were present.

[a] Significant results.

[b] Significant 2-way interaction for group × side.

muscle groups are equal in strength.[20] In a study of adolescent gymnastic athletes,[21] ratios of 1.24 and 1.35 were found. This population is comparable to our group of swimmers, given the serratus anterior dominance in both gymnastics and swimming and the bilateral use of the upper extremities. However, the control group of gymnasts also showed ratios that were higher than the standard value of 1 (range, 1.20–1.21). Cools et al[21] suggested that the higher ratios might be related to adolescent muscle characteristics and not to sport-specific adaptations.

Furthermore, values greater than 1 were also noted in other athletes,[7,10,11] so muscle balance may favor a specific sport. Therefore, comparisons of muscle balance should be made within each sport and not with the 1:1 value found in nonathletes. The question arises as to whether this altered muscle balance might be an adaptation only or a possible injury risk factor. Prospective studies of larger groups of athletes are needed to identify possible risk factors, such as muscle balance.

In addition to evaluating muscle strength, we investigated muscle endurance. We used the FI to measure the degree of muscle fatigue after 40 repetitions. During the pretraining test, the FI values were all negative. This means that the endurance test resulted in increased work between the first third and last third of the 40 repetitions. The swimmers had good muscle-endurance capacity, which is a positive result. However, the large SDs indicate much intersubject variability. Compared with a previous study[21] of gymnasts and a control group of nonathletic adolescents performing the same protocol, the swimmers had more muscle endurance. Increased muscle endurance might be a sport-specific adaptation in swimmers, although further research is necessary to exclude other possible factors, such as the specificity of the protocol.

Swimming is considered a symmetric sport, but side-to-side differences in strength are reported in the literature. Several authors[29,30] found side-to-side differences in isokinetic glenohumeral rotational strength in swimmers. Values were significantly higher for external-rotation strength in the dominant shoulder. We also noted side-to-side differences, with significant results for retraction. A unilateral breathing pattern during freestyle may explain this phenomenon. When breathing to one side, the contralateral side must stabilize the body, which requires a good deal of muscle activity. However, many swimmers are bilateral breathers. In these athletes, the effects of arm dominance in daily activities could be responsible for side-to-side differences. Regarding the important function of the trapezius muscle in scapular stability,[7] side-to-side differences in strength can lead to scapular asymmetry. Thus, for injury prevention in swimmers, achieving bilateral symmetry may be very valuable. With respect to muscle endurance, some side-to-side differences were present, with muscle endurance lower on the dominant side. From a clinical point of view, it may be important to enhance symmetry rather than muscle endurance.

## Evaluation of Training Programs

**Group Differences.** We found no group differences for any evaluated factors. Strength training and muscle-endurance training seemed to have similar effects on swimmers' strength improvement. In his classic 1945 work, Delorme[28] suggested that a resistance-training program using a low number of repetitions and high resistance favors adaptations in strength, whereas training with a high number of repetitions and low resistance increases muscle endurance. In a more recent study, Campos et al[31] compared 3 different modalities of lower extremity strength training in healthy young men. Maximal strength and muscle endurance were measured before and after a training program. One group performed 4 sets of 3- to 5-repetition maximums, the second group performed 3 sets of 9- to 11-repetition maximums, and the third group performed 2 sets of 20- to 28-repetition maximums. They found an overall significant improvement in maximal strength, similar to our results. However, muscle endurance increased significantly only in the group performing the greatest number of repetitions. This finding contrasts with the present results, but we should note that our test population and the muscles examined in this study were different. The additional swimming training in our study could be an important factor as well and might explain some differences between our results and those of Campos et al.[31] Hagberg et al[32] compared isometric shoulder-strength training with isometric shoulder-endurance training in women with neck and shoulder pain. Shoulder-endurance training was less successful than strength training in improving muscle endurance. The authors recommended strength training in addition to shoulder-endurance training rather than endurance training alone. Yet the study focused only on women with neck and shoulder pain, making comparisons with our swimmers difficult.

Another factor is the different number of repetitions between the test (40) and training situations (20) in our investigation. For a sport-specific approach, we might consider an alternative training modality. This has already been suggested by Van Heuveln,[33] who concluded that stroke rates in swimming could be the basis for a strength program. A 100-m freestyle swimmer performs about 50 strokes during his race; therefore, the number of repetitions during strength training should also be 50. However, this proposal has not yet been investigated.

**Time Differences.** For protraction, we noted a main effect of training, indicating that peak forces for the protractors were higher after training. Still, given the dominant role of the serratus anterior[4] in swimming, it is unclear whether the improvement resulted from the strength program alone or a combination of the strength program and swimming-training sessions. An additional study with a control group performing complete swimming training would be useful. For retraction, strength increased only on the nondominant side. Because the trapezius muscle is not a major source of propulsion force[4] in swimming, it is very likely that strength training caused this increase. Asymmetry could explain these findings. At the start of the study, the nondominant side was slightly weaker. Considering that the same amount of weight and number of repetitions were used bilaterally, we would expect strength to increase more on the weaker side.

Neither of the training programs had a positive influence on muscle endurance. All FIs became positive, demonstrating less muscle endurance in our test population after 12 weeks of swimming combined with a strength-training or muscle-endurance program. In terms of injury prevention, decreased muscle endurance is not a desirable outcome. Fatigue of the scapular retractor muscles may lead to additional protraction, which can result in anterior translation of the humeral head, narrowing of the subacromial space, and impingement.[6,34] Furthermore, fatigue of the serratus anterior muscle may restrict upward scapular rotation in swimmers, which also increases the risk of impingment.[5,6] The decreased muscle endurance we noted may be from the swimming training; it is likely that swimming training causes fatigue in both the serratus anterior and trapezius. We suggest that 12 weeks of intensive swimming training caused fatigue in the scapular muscles, resulting in less muscle endurance. Su et al[6] demonstrated fatigue after a single training session, which supports our hypothesis. Our findings indicate the importance of preventing scapular muscle fatigue in programs for injury prevention. However, the training program modality should be further explored. Beach et al[30] found a strong negative correlation between isokinetic muscle-endurance values and shoulder pain in swimmers. Swimmers with low levels of muscle endurance had shoulder pain, although we must recognize that Beach et al examined the glenohumeral rotator muscles, whereas we studied the scapular muscles, and used a test protocol of 50 repetitions at 240°/s, compared with our protocol of 40 repetitions at 160°/s.

Protraction/retraction ratios were altered as a result of the training program. Compared with pretraining testing, the strength ratio remained the same for the dominant side but decreased on the nondominant side. Increased peak force for retraction on the nondominant side explains the altered protraction/retraction ratio. Overall, these ratios can be considered satisfactory because of the absence of large muscular imbalances.

After the training period, trapezius muscle strength was more symmetric, which may be valuable in terms of injury prevention. In a bilateral sport such as swimming, achieving a greater degree of left to right symmetry may be particularly important.

**Limitations.** Care should be taken when attempting to generalize our results. The swimmers were team members of equal swimming levels and ages, making comparisons possible. However, these results are very specific for the defined swimming-level and age groups. An older or more experienced population may show more and different sport-specific adaptations. Further research with respect to swimming level and age would be beneficial to investigate these factors.

Also, the testing position during isokinetic evaluation may need to be addressed. The swimmer sat with the arm elevated in the scapular plane, which is not a swimming-specific position. Because about 80% of swimming practice time is spent performing freestyle, a prone testing position may be more suitable for swimmers.[30] Falkel et al[35] found that this test position provided useful results for isokinetic glenohumeral rotation in swimmers: swimmers' shoulder strength was greater in the prone position than in the supine position ($P < .05$).[35] Thus, this position may also result in higher values for the scapular muscles. However, further research is necessary to investigate the influence of different testing positions.

Our study was focused on muscle strength and endurance only in the shoulder area. Therefore, we did not consider some other factors involved in swimming. For example, we did not take into account other links of the kinetic chain. The kinetic chain principle describes how the human body can be considered as a series of interrelated links or segments.[7] Swimming requires whole-body activation, so the concept of the kinetic chain might be very important in this sport. Core stability especially may be essential in swimming to maintain stability in water. Additional studies examining other parts of the kinetic chain will provide further descriptions of swimmers' characteristics.

Finally, the absence of a control group can be considered a limitation. Whether these results are specific to the swimming population or characteristic of adolescents in general is unknown.

## CONCLUSIONS

This study represents one of the first steps in the description of sport-specific adaptations in the scapular-muscle performance of young swimmers. Scapular-muscle performance was characterized by increased protraction strength and side-to-side differences. Further research is necessary to determine whether these adaptations increase injury risk. After finishing the scapular-training program, muscular balance and side-to-side symmetry were altered. On the nondominant side, the protraction/retraction ratio decreased to 0.93 (compared with 1.23 before training). The side-to-side differences in retraction force noted initially were not present at the posttraining test. Less muscular imbalance and more left-to-right symmetry can be considered important issues in preventing injuries among swimmers. However, after 12 weeks of concurrent swimming and strength training, muscle endurance was less than before training. The finding that muscle endurance was not improved by our training program may be the result of exhaustion, either as a consequence of swimming training itself or in combination with strength training. Collecting more information concerning sport-specific adaptations in swimmers is the first goal in further research.


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**COMMENTARY**

# COMMENTARY


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I would like to commend the authors on their work. This study to a large extent mirrored the published work by Cools et al,[1] albeit in a different population. Unique to the present work, however, is the investigation of 2 types of training programs on muscle-performance characteristics in adolescent swimmers. Specifically, after isokinetic pretesting of the scapular protractors and retractors, swimmers performed a supervised program of either strength training or endurance training for 12 weeks, followed by a posttest. The authors did not identify differences in muscle performance between groups after the intervention for any of the dependent measures. Furthermore, the authors reported that muscle endurance, as a function of the fatigue index (FI), decreased between the 2 measures.

Identifying differences between groups and among multiple interventions is influenced by several factors, including variance among the groups, sample size, and the effect size(s) of the intervention(s).[2] In this study, the authors acknowledge that intersubject variance (large SDs) may have contributed to the inability to detect a difference between groups in isokinetic muscle performance measures after the intervention programs. Although this may be a contributing factor, it is my opinion that the inability to identify group differences was minimally influenced by this factor. Additionally, even though the group sizes were small, larger group sizes in this situation would likely have done very little to increase the chance of identifying a statistical, let alone clinically important, difference between groups. The underlying reason the authors were unable to detect differences between groups was probably a function of the similarities in intervention programs. This statistical information could have been ascertained by performing a prospective pilot study. Armed with the information from an a priori pilot study, the authors could have calculated the sample size necessary to identify a statistical difference or realized that the training programs were so similar that further pursuit of the study was not likely to demonstrate differences. Arguably, there are times when identifying no differences between interventions is clinically important. In these cases, when the investigators expect to find no difference, it becomes even more critical to conduct a power analysis. At this juncture, given that neither a pilot study nor power analysis was performed, it would have been helpful to the reader had the authors reported the actual effect sizes ($\eta^2$).

With regard to muscle endurance, participants performed a fatigue test (40 repetitions at 180°/s) before and after the training programs. During the pretest, the authors found a negative FI, which indicates that work increased when the data from the last third of the fatigue protocol were compared with those of the first third. The authors reported, "The swimmers had good muscle-endurance capacity, which is a positive result." During the posttest, however, the authors found a positive FI, indicating that work decreased when the last third of the fatigue protocol was compared with the first third. The authors interpreted this result as signifying that the swimmers had less muscle-endurance capacity after training. They theorized that swimming in conjunction with the training program may have created a situation involving overtraining. They attempted to substantiate their findings by citing the work of Su et al,[3] who observed decreased muscular endurance after an acute bout of swimming. Although it is possible that the swimmers became overtrained during the 12-week study, this logic would not explain the results of their FIs. Overtrained or not, the participants' ability to generate force should have been greater at the onset (ie, during the first third of the fatigue protocol) and less during the final phase (ie, during the last third of the protocol). Su et al[3] did identify a decrease in shoulder force production after an acute bout of swimming, reinforcing the fact that the ability to generate force decreases after a period of acute exertion. The factor that most likely explains the negative FI is simply a learning effect. The authors cite reliability data related to the Biodex for the motions of protraction and retraction,[4] but these data were not specific to the faster speed at which the fatigue test was conducted. Although the participants performed a brief (5-trial) familiarization session, this was obviously insufficient. The data from the present study indicate that during the pretest, the participants learned how to use the device; hence, force readings were greater in the last third of the test than in the first third. They retained this experience, and I believe that the posttest data are valid. However, I disagree with the interpretation of the posttest data and suggest that these data are consistent with a normal fatigue test, as shown in other similar work.[1]

Despite these weaknesses, the strength of the current study is the descriptive muscle-performance data in adolescent swimmers. These data are of potential value to researchers and clinicians who work with this population.

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## AUTHORS' REPLY

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original research

# Balance Performance With a Cognitive Task: A Continuation of the Dual-Task Testing Paradigm

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***Context:*** To ensure that concussed athletes return to play safely, we need better methods of measuring concussion severity and monitoring concussion resolution.

***Objective:*** To develop a dual-task model that assesses postural stability and cognitive processing in concussed athletes.

***Design:*** Repeated measures study.

***Setting:*** University laboratory.

***Patients or Other Participants:*** Twenty healthy, college-aged students (10 men, 10 women; age = 20 ± 1.86 years, height = 173 ± 4.10 cm, mass = 71.83 + 35.77 kg).

***Intervention(s):*** Participants were tested individually in 2 sessions separated by 2 days. In one session, a balance task and a cognitive task were performed separately. In the other session, the balance and cognitive tasks were performed concurrently. The balance task consisted of 6 conditions of the Sensory Organization Test performed on the NeuroCom Smart Balance Master. The cognitive task consisted of an auditory switch task (3 trials per condition, 60 seconds per trial).

***Main Outcome Measure(s):*** For the balance test, scores for each Sensory Organization Test condition; the visual, vestibular, somatosensory, and visual-conflict subscores; and the composite balance score were calculated. For the cognitive task, response time and accuracy were measured.

***Results:*** Balance improved during 2 dual-task conditions: fixed support and fixed visual reference ($t_{18} = -2.34$, $P < .05$) and fixed support and sway visual reference ($t_{18} = -2.72$, $P = .014$). Participants' response times were longer ($F_{1,18} = 67.77$, $P < .001$, $\eta^2 = 0.79$) and choice errors were more numerous under dual-task conditions than under single-task conditions ($F_{1,18} = 5.58$, $P = .03$, $\eta^2 = 0.24$). However, differences were observed only during category-switch trials.

***Conclusions:*** Balance was either maintained or improved under dual-task conditions. Thus, postural control took priority over cognitive processing when the tasks were performed concurrently. Furthermore, dual-task conditions can isolate specific mental processes that may be useful for evaluating concussed individuals.

***Key Words:*** posture, stability, executive function, response time, concussions, mild traumatic brain injuries

**Key Points**

- Under a dual-task condition (balance task plus cognitive task), postural control appeared to take priority over cognitive processing.
- Measuring cognitive processes involved in performing complex, computer-based tests during the simultaneous performance of a balance task may provide a sensitive means of detecting subtle cognitive changes in patients with concussions.

McCrea et al[1] reported in 2002 that 90% of the more than 2 000 000 traumatic brain injuries that occurred annually in the United States were classified as concussions. In 2006, Langlois et al[2] estimated that approximately 1.6 to 3.8 million sport-related concussions occur annually.[2]

This alarming rate of sport-related concussions warrants improved methods of measuring concussion severity and resolution in order to determine appropriate time frames for safe return to play. Clinicians use a variety of tools, including self-reporting of symptoms, neuropsychological testing, and postural-stability assessment to track concussion resolution and ultimately identify a time frame for returning the athlete to play. Although a number of tests have been linked to traumatic brain injury, none has been shown to be the sole indicator of concussion occurrence and/or resolution.[3]

Several experiments have been conducted in which participants perform a balance task while simultaneously engaging in a mentally challenging cognitive task. Hunter and Hoffman[4] had participants perform visual and auditory cognitive tasks while in tandem stance on a force plate to measure postural sway. Compared with the single-task condition, decreased sway velocity was observed during the dual-task condition, which resulted in increased medial-lateral and anterior-posterior center-of-pressure (COP) sway. The authors[4] hypothesized that dual-task conditions decreased muscle activation, allowing for less COP movement, and suggested that the single-task balance conditions increased attention allotted to balance, eliciting increased muscle tension and resulting in increased COP medial-lateral and anterior-posterior sway. Other research suggests that incorporating a visual task while balancing decreases COP range and speed. Broglio et al[5] evaluated the interrelation between balance perturbation and a visual cognitive-switch task designed to assess executive function (ie, planned, goal-directed behavior). Balance perturbations were elicited by the Smart Balance Master Sensory Organization Test (SOT) (NeuroCom International, Inc, Clackamas, OR). Participants performed 4 SOT conditions that incorporated only visual input. The balance protocol was performed separately or concurrently with a visual cognitive-switch task. Compared with single-task conditions, participants' SOT balance scores improved. Response times increased in a linear fashion across the 4 balance conditions, which were progressively more demanding. These results indicate that under dual-task conditions, balance control takes priority, with cognitive functions becoming more impaired as balance perturbation increases.[5]

Although some studies provide evidence that posture is maintained at the expense of cognitive functioning, other authors report the opposite. Barra et al[6] used spatial and verbal tasks in conjunction with a balance task performed by young, healthy adults and reported an increase in falls during spatial-task performance. The authors concluded that cognitive performance was maintained at the expense of balance, but the use of a safety rail may have resulted in increased risk-taking behavior by participants. Researchers[7] have shown decrements in balance during concurrent performance of a cognitive task conducted primarily in middle-aged to older-aged samples.

The purpose of our study was to investigate the dual-task method as a possible sport-related concussion-assessment tool. This study replicated and extended previous work[5] by including both visual and nonvisual SOT conditions in the protocol, increasing the length of each trial to 60 seconds, and incorporating an auditory executive-function task. Our hypothesis was that sway would decrease, whereas cognitive performance, measured as response time and accuracy, would worsen.

## METHODS

### Participants

Twenty healthy, college-aged students recruited from exercise science classes participated in this study (10 men, 10 women; age = 20 ± 1.86 years, height = 173 ± 4.10 cm, mass = 71.83 ± 35.77 kg). Men and women were included in equal numbers to reduce any potential sex bias. Twenty participants were recruited to achieve a large effect size (d = 0.75), as suggested by prior research and power calculations.[8,9] Volunteers were excluded if they had a history of concussion, English was not their primary language, or they were receiving treatment for a lower extremity injury.

### Tests

**Balance Test.** Testing consisted of a modified SOT that comprised 6 conditions developed for balance assessment: fixed surface and fixed vision (fixed-fixed), fixed surface and absent vision (fixed-absent), fixed surface and sway-referenced vision (fixed-sway), sway-referenced surface and fixed vision (sway-fixed), sway-referenced surface and absent vision (sway-absent), and sway-referenced surface and sway-referenced vision (sway-sway) (Figure 1). The length of each trial was extended to 60 seconds (standard is 20 seconds). Sway gain was set at 1.0, matching sway referencing to the participant's sway as described in the *System Operator's Manual*.[8] Each participant underwent each of the 6 conditions 3 times, for a total of 18 separate trials.[10] Each trial lasted 60 seconds, and each volunteer was given a 15-second rest between trials. During those 15 seconds of rest, data calculation for the previously performed balance trial was completed. The 18 trials were randomized to minimize practice effects.

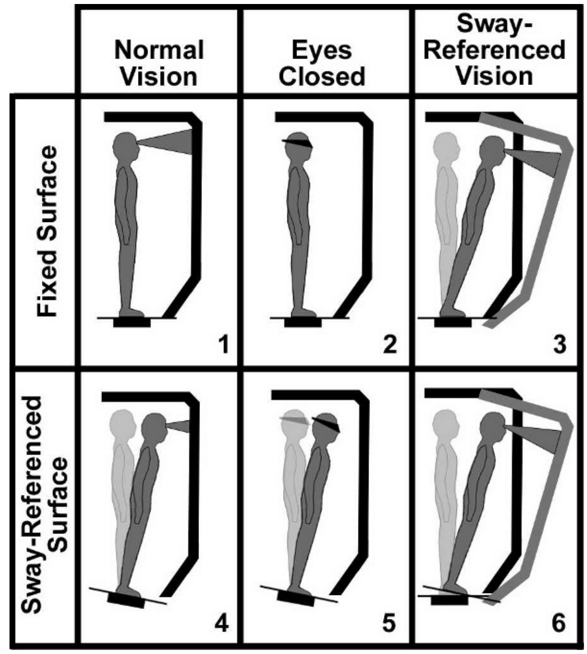


**Figure 1. Six conditions of the Sensory Organization Test. Used by permission of NeuroCom International, Inc.**

**Cognitive Test.** The cognitive task was an auditory switch test that involved the presentation of 40 computer-generated letters or numbers via a commercial software program (SuperLab version 2.01; Cedrus Corporation, San Pedro, CA) to a headphone. The letters consisted of 5 vowels (A, E, I, O, and U) and 5 randomly selected consonants (B, D, L, C, and J). The numbers consisted of 4 even numbers (2, 4, 6, and 8) and 4 odd numbers (1, 3, 5, and 7). Participants responded to each stimulus by pressing a key on a serial mouse (even number: left key, odd number: right key, vowel letter: left key, consonant letter: right key). Each key press was followed 100 milliseconds later by the presentation of the next stimulus. Letters or numbers were presented as 1 stimulus or 2 or 3 stimuli. The letter-number category discrimination switched after each series. The initial 4 trials of each test were considered practice and were not evaluated. The remaining 36 trials consisted of 24 nonswitch trials (ie, repetitive, within-category discriminations) and 12 switch trials (ie, a change in category discrimination), with an equal number of switches to even-odd and vowel-consonant conditions. Response times and response accuracy were recorded for each trial. The test terminated with a computer-generated command to stop. A set of 36 unique tests was developed in which the order of blocks of nonswitch and switch trials was randomized.

Each participant was trained to perform the auditory switch task in 5 phases. Initially, the task was described to the participant, who stood next to a computer station. He or she was directed to attend to a chart at eye level that described the correct stimulus-condition and mouse-key response pairings. Next, the volunteer donned a set of headphones, was instructed to hold the mouse in the right hand with both arms at the side, and was then asked to monitor a series of 15 letters and numbers stimuli presented every 500 milliseconds (adjusting the loudness of the stimuli to the preferred level via a volume-adjustment dial on the headphone cord). The participant was directed to listen to a series of 30 numbers and to discriminate between even and odd numbers with the appropriate mouse-key press. A series of 30 letters was presented and the participant was asked to discriminate between vowels and consonants with the appropriate key press. Finally, he or she was told that both letters and numbers were going to be presented and to respond as quickly and accurately as possible. Stimuli consisted of 120 letters or numbers, which were repeated in series lengths of 1, 2, or 3 and then switched from one category to the other. There were 80 nonswitch and 40 switch trials, with an equal number of switches to even-odd and vowel-consonant conditions.

### Procedures

Participants read and signed a consent form approved by the institutional review board, which also approved the study, and completed a brief questionnaire of self-reported demographics. Testing consisted of 2 sessions separated by 48 to 72 hours, performed at the same time of day. During session 1, each participant was familiarized with the balance and cognitive protocol by completing truncated versions of the full tests. For the balance task, participants completed 10 seconds of 1 trial of all 6 conditions. For the cognitive task, participants completed shortened versions of both the nonswitch and switch tasks.

The balance test was conducted by trained researchers using the Smart Balance Master (NeuroCom) in concert with the Data Acquisition Toolkit (version 2.0; NeuroCom). The latter portion of the first session consisted of 1 of 2 scenarios: in the first, the cognitive and balance tasks were performed separately (single task); in the second, the cognitive and balance tasks were performed concurrently (dual task). The unused protocol, either single task or dual task, was used for the second testing session. Sessions 1 and 2 were counterbalanced across participants. The single-task and dual-task conditions were delivered by 1 and 2 investigators, respectively. For the single-task balance condition, volunteers were provided the same instructions as given in the practice session, that is, to respond to the cognitive stimuli as quickly and accurately as possible. After initiation of data collection, no verbal cues were given. Data were collected for the eighteen 60-second trials. After completion of the balance task, the participant was asked to step out of the device and prepare for the cognitive task. The dual-task session began with instructions. After confirming that the participant understood the procedure, testing began with a volume-adjustment trial and a 120-trial practice test, which was administered to the participant while he or she was standing next to the computer station. The participant was then instructed to step on the platform and to perform the cognitive test while maintaining balance under 6 test conditions. Each balance and cognitive test began simultaneously. Each participant finished the cognitive test before completing the balance trial.

### Data Analysis

**Balance Assessment.** The initial 5 and final 20 seconds were discarded from data analysis to limit extraneous and between-subjects variability associated with the beginning and completion of the dual-task protocol. Scores for each SOT condition; visual, vestibular, somatosensory, and visual-conflict subscores; and a composite balance score were calculated from data obtained during the remaining 35-second period in which dual-task conditions were in effect. Scores were derived as described in the *System Operator's Manual*.[8] We used paired *t* tests to assess differences between scores obtained from the single-task and dual-task protocols for condition; visual, vestibular, somatosensory, and visual-conflict; and composite ratio scores. The data obtained from 1 male participant were excluded from analyses due to extreme SOT scores, which were below the normative data provided by NeuroCom for both the single-task and dual-task protocols. The exclusion of this participant did not affect the overall power of the study.[11]

**Cognitive Assessment.** Cognitive test performance was assessed by evaluating each participant's response time (RT) and response accuracy to stimuli presented on trials immediately before a category switch (nonswitch trials) and to stimuli presented immediately after a category switch (switch trials). Participants' RTs and proportion of response errors were averaged over 3 successive tests performed under the single-task condition and 3 tests performed under each of the 6 dual-task conditions. The RT scores and response errors were analyzed separately via a within-subjects 2 (trial type: nonswitch, switch) $\times$ 2 (test condition: single task, dual task) $\times$ 6 (balance conditions) analysis of variance. All data were analyzed using SPSS (version 15.0; SPSS Inc, Chicago, IL). Sample size was estimated using a large effect size (d = 0.80) from previously related research.[4]

## RESULTS

### Balance Assessment

Differences in balance scores were noted between 2 of the 6 conditions. Scores were higher under during the dual-task fixed-fixed ($t_{18} = -2.35$, $P = .030$) and fixed-sway ($t_{18} = -2.72$, $P = .014$) conditions. Condition, subscore, and composite means and SDs for the 35-second assessment of balance during single-task and dual-task conditions are provided in the Table.

### Cognitive Assessment

Response times were longer for switch trials than nonswitch trials under both single-task and dual-task conditions ($F_{1,18} = 67.77$, $P \leq .001$, $\eta^2 = 0.79$). An interaction was noted for response time between trial type (nonswitch versus switch) and test condition (single task versus dual task) ($F_{1,18} = 5.084$, $P = .037$, $\eta^2 = 0.22$). As

**Table. Balance-Task Condition Scores, Subscores, and Composite Scores (Mean ± SD)[a]**

| Balance Condition | Balance Test Only | Dual Task (Balance Test + Cognitive Test) |
|---|---|---|
| 1 (fixed surface, fixed vision) | 89.5 ± 6.0 | 91.6 ± 3.4[b] |
| 2 (fixed surface, absent vision) | 86.0 ± 5.3 | 88.0 ± 3.2 |
| 3 (fixed surface, sway-referenced vision) | 84.1 ± 9.5 | 89.7 ± 4.2[c] |
| 4 (sway-referenced surface, fixed vision) | 85.2 ± 7.8 | 85.2 ± 5.4 |
| 5 (sway-referenced surface, absent vision) | 72.7 ± 9.5 | 73.9 ± 7.4 |
| 6 (sway-referenced surface, sway-referenced vision) | 71.5 ± 10.5 | 71.7 ± 7.0 |
| Visual | 95.0 ± 9.4 | 92.5 ± 4.5 |
| Vestibular | 81.0 ± 11.1 | 80.3 ± 7.8 |
| Somatosensory | 96.5 ± 8.4 | 95.7 ± 2.4 |
| Visual conflict | 99.4 ± 9.7 | 100.2 ± 5.1 |
| Composite score | 91.4 ± 5.7 | 93.2 ± 3.5 |

[a] The range of possible scores is 0 to 100.
[b] $P < .05$.
[c] $P \leq .05$.

seen in Figure 2, RT during dual-task conditions was longer than during single-task conditions but only for switch trials. Analyses of response errors yielded main effects for trial type ($F_{1,18} = 5.58$, $P = .03$, $\eta^2 = 0.24$), which were qualified by a trial type × test-condition interaction ($F_{1,18} = 8.35$, $P = .01$, $\eta^2 = 0.32$). As shown in Figure 3, participants made more errors during dual-task conditions but only on switch trials.

## DISCUSSION

The purpose of our study was to investigate the effects of introducing visual and nonvisual conditions of the SOT in conjunction with an auditory cognitive task on balance and cognitive performance. Our results confirmed and extended the findings obtained by Broglio et al,[5] which indicated that balance would be maintained at the expense of cognitive function with regard to both RT and errors. Similar to prior researchers,[4,5,7,12] we found that young adults' postural stability increased during the fixed-fixed and fixed-sway conditions and remained unchanged during the remainder of the balance conditions. With respect to the cognitive task, we observed a concomitant increase in RT and number of errors with increasing difficulty of the balance task.

A physiologic explanation of our findings is that cerebral processing during dual-task conditions apparently modifies how the central nervous system controls postural stability. Under normal conditions, balance is controlled via integration of sensory information provided by the visual, vestibular, and somatosensory systems.[5,13] Input based on limb positioning is transmitted to the basal ganglia. This signal is integrated with planned actions developed in the premotor cortex and supplementary motor cortex in the cerebellum. The descending pathway continues via alpha motor neurons, which innervate skeletal muscle, allowing

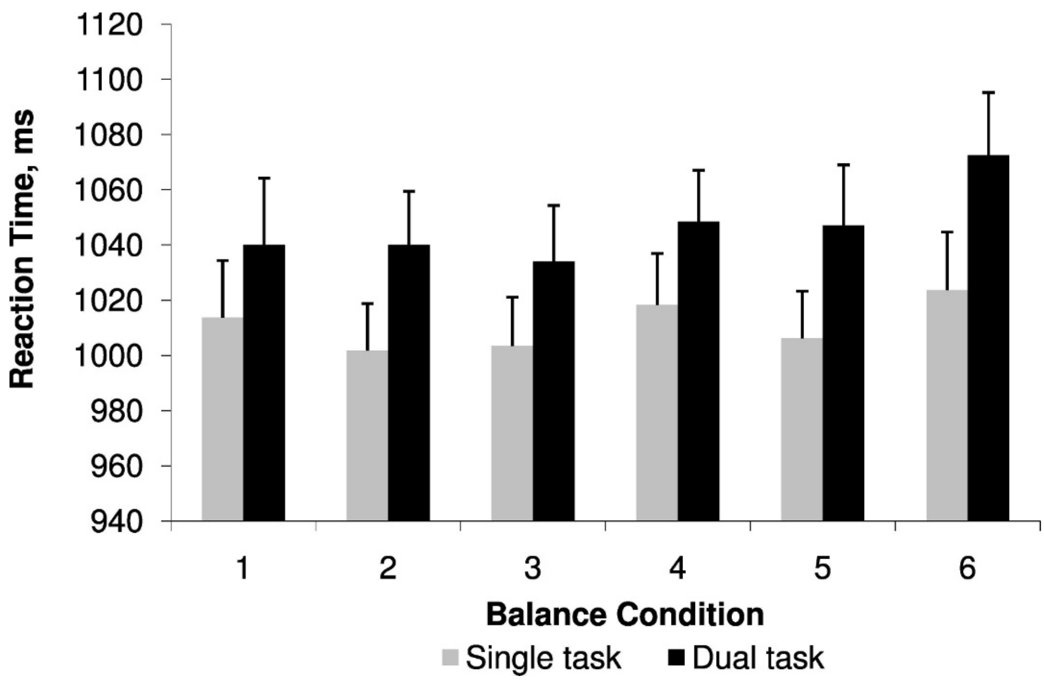


**Figure 2. Reaction time for single-task and dual-task methods for 6 balance conditions: (1) fixed surface, fixed vision; (2) fixed surface, absent vision; (3) fixed surface, sway-referenced vision; (4) sway-referenced surface, fixed vision; (5) sway-referenced surface, absent vision; (6) sway-referenced surface, sway-referenced vision.**

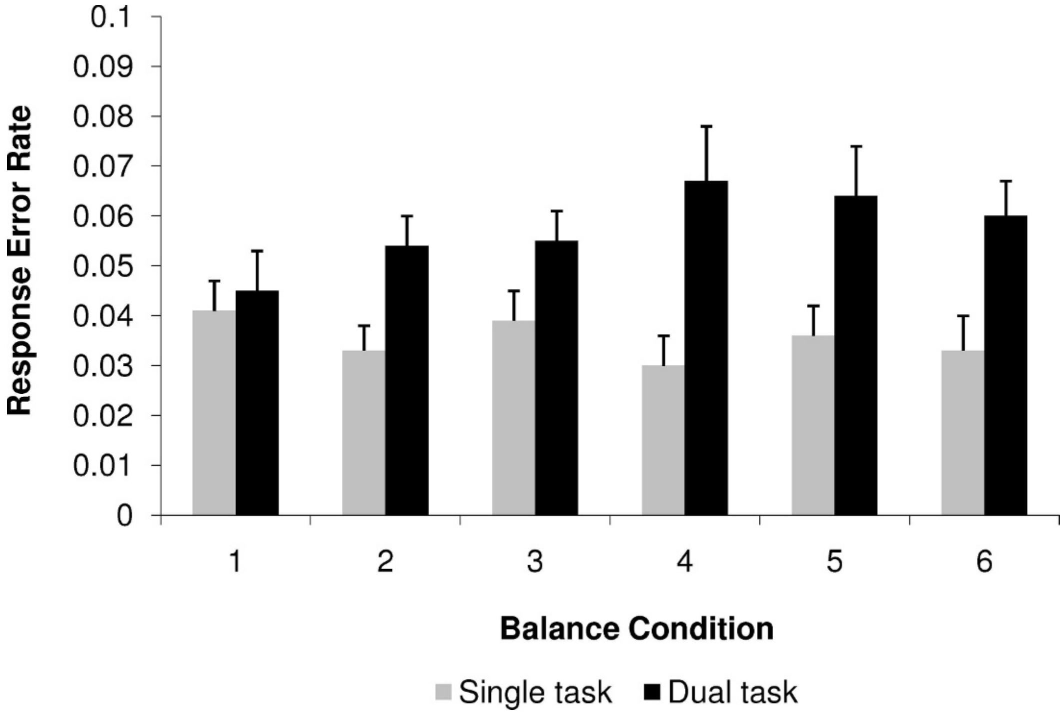


**Figure 3. Errors in single-task and dual-task methods for 6 balance conditions: (1) fixed surface, fixed vision; (2) fixed surface, absent vision; (3) fixed surface, sway-referenced vision; (4) sway-referenced surface, fixed vision; (5) sway-referenced surface, absent vision; (6) sway-referenced surface, sway-referenced vision.**

for regulation of balance.[5,14,15] Typically, the visual and somatosensory inputs provide the majority of information to maintain postural stability.[5,16]

Theoretically, our findings support the "posture-first" principle, which suggests that postural control is attentionally demanding, requiring increased allocation of attentional resources in accordance with the complexity of the postural task.[17,18] Vuillerme and Nafati[19] proposed 2 additional hypotheses to account for the maintenance of or increase in postural stability during the dual-task condition. The first suggests that increased attention during a reaction-timed cognitive task increases muscular stiffness and, subsequently, postural control.[19] This hypothesis was supported by Hunter and Hoffman,[4] who found decreased medial-lateral COP movement during a balance task in participants simultaneously performing a visual cognitive task.

The second hypothesis suggests that dual-task conditions facilitate control at the sensory-motor level.[20] Although attentionally demanding, postural stability occurs primarily via automatic processes in everyday life, making a single-task condition involving balance alone somewhat unnatural. The authors[19] of a related study instructed a sample of young participants to focus on reducing their sway, compared with a control group who received no instruction during a quiet-standing task. The experimental group, which allocated additional attention to reduce postural sway, had increased COP and center-of-gravity amplitudes and frequencies. Incorporating a secondary cognitive task into the dual-task method may better represent everyday and sport situations and force individuals to allocate attention to the secondary cognitive task, leaving postural stability to the aforementioned automatic processes. Simply stated, deliberately controlling posture is less efficient than controlling posture more automatically.[20]

In contrast to our results, decrements in balance during a cognitive task have been reported by Peterson,[21] who observed compromised balance in gymnasts performing a cognitive task. Although an important finding, the author's use of a gross measure of balance (ie, walking on a balance beam) and cognitive task (serial sevens) did not allow subtle neurocognitive changes to be captured.[5,21] These results are similar to those found in an older sample but opposite those found with a dual-task procedure in younger participants,[7] who may possess greater ability to allocate attention. This ability may allow for muscle recruitment to maintain or improve postural stability with increased RT and error response rates during the dual-task protocol.

Our results are similar to those observed by Broglio et al.[5] Participants' performance on an auditory executive-function task that assessed speed and accuracy revealed longer RTs under dual-task than single-task conditions. Notably, longer RTs and an increase in response errors were observed during dual-task conditions for trials that followed a category switch (consonants to vowels or odd numbers to even numbers) versus for trials in which the stimulus category did not change. Thus, the perturbation of balance produced specific effects on cognitive functioning. In addition, the increased complexity of the cognitive task demanded executive processing to inhibit responses to one stimulus set and to respond to a different, now relevant, stimulus set. The process-specific effects of balance disruption on cognitive performance may help to explain, at least in part, the conflicting results obtained by previous researchers who used cognitive tasks that did not depict subtle cognitive changes.

One limitation of this investigation was our study of a healthy sample to determine whether cognitive deficits existed in a nonconcussed state and to evaluate the dual-tasking model as a possible concussion-assessment test. Further research regarding this dual-task condition protocol will include a concussed sample for comparison. Other limitations were participant motivation and frustration during completion of the cognitive task. Although participant compliance and effort were considered good, extraneous variables such as these can only be controlled to a certain extent.

Our results are particularly important for researchers interested in assessing the effects of concussion on athletes' cognitive function. Currently, no single evaluative test can determine the effect of a concussion on cognitive function and help clinicians make return-to-play decisions. The relationships among self-reported symptoms, computerized neuropsychological testing, and postural stability are well documented in the concussion literature. When delivered separately, these tools have demonstrated sensitivities of 68%, 79%, and 62%, respectively; when delivered together, greater than 90% sensitivity was achieved.[22] Although these results are encouraging, not all clinicians have access to these tests due to financial constraints and limited availability of the professional support needed to properly evaluate such tests.

The results of the present study suggest that measures of cognitive processes involved in performing complex computer-based tests while concurrently performing a balance task may provide a sensitive means of detecting subtle cognitive changes in a young, healthy sample. Although our findings show promise as an alternate tool for concussion assessment, continued research on a concussed sample is imperative before we implement this protocol in the management of concussion. Like any tool used for clinical decision making, each evaluative tool suggested to help in the management of sport-related concussion must meet the stringent criteria of the laboratory setting before being used in clinical practice.[9,23,24] Our methods may be more academic and laboratory based, but the results provide meaningful contributions to aid in the development of a more clinically based tool. A novel tool that incorporates both a motor and a cognitive task to detect deficiencies associated with sport-related concussion may prove to be both time- and cost-effective for the clinician.

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# Development of a Heat-Illness Screening Instrument Using the Delphi Panel Technique

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***Context:*** Exertional heat illness (EHI) is the third leading cause of death among athletes, but with preparticipation screening, risk factors can be identified, and some EHIs can be prevented.

***Objective:*** To establish content validity of the Heat Illness Index Score (HIIS), a 10-item screening instrument designed to identify athletes at risk for EHI during a preparticipation examination.

***Design:*** Delphi study.

***Setting:*** The Delphi technique included semistructured face-to-face or telephone interviews and included electronic questionnaires administered via e-mail.

***Patients or Other Participants:*** Six individuals with extensive research experience and/or clinical expertise in EHI participated as expert panelists.

***Main Outcome Measure(s):*** We used a Delphi panel technique (3 rounds) to evaluate the HIIS with the consensus of expert opinions. For round 1, we conducted face-to-face interviews with the panelists. For round 2, we solicited panelists' feedback of the transcribed data to ensure trustworthiness, then provided the participants with the revised HIIS and a questionnaire eliciting their levels of agreement for each revision from the previous round on a visual analog scale (11.4 cm) with extreme indicators of *strongly disagree* and *strongly agree*. We calculated the mean and SD for each revision and accepted when the mean was greater than 7.6 cm (*agree*) and the SD still permitted a positive response (>5.7 cm), suggesting consensus. For round 3, we instructed participants to indicate their levels of agreement with each final, revised item and their levels of agreement with the entire instrument on a 4-point Likert scale (1 = *strongly disagree*, 4 = *strongly agree*).

***Results:*** In round 1, panelists supported all 10 items but requested various revisions. In round 2, 16.3% (7 of 43) revisions were rejected, and 2 revisions were modified. In round 3, 100% of panelists reported agreeing (n = 3 of 6) or strongly agreeing (n = 3 of 6) with the final instrument.

***Conclusions:*** Panelists were able to achieve consensus and validated the content of the HIIS, as well as the instrument itself. Implementation and further analysis are necessary to effectively identify the diagnostic accuracy of the HIIS.

***Key Words:*** Heat Illness Index Score, preparticipation physical examination, exertional heat illnesses, risk assessment

**Key Points**

- Using the Delphi panel technique, we established content validity of the Heat Illness Index Score instrument with 3 rounds of panelist consensus.
- The Heat Illness Index Score instrument needs more revision and needs implementation to establish diagnostic accuracy and clinical usefulness.

Exertional heat stroke is the third leading cause of death in the United States among high school athletes,[1] and, with effort to reduce risk factors, many heat illnesses can be prevented.[2–4] Screening athletes during preparticipation physical examinations (PPEs) can help health care professionals identify predisposing factors of exertional heat illnesses (EHIs). Using the PPE to identify patients at risk for EHI can provide the athletic trainer (AT) with information about predisposing conditions that might not otherwise be disclosed.[5,6] Subsequent action to reduce these risks is an essential component of the prevention process. Typically, the PPE includes an evaluation of general medical considerations and orthopaedic injuries; however, ATs would be better equipped to prevent injury and illness with more information about any previous history of cardiovascular, respiratory, and heat illnesses.[5–7]

The recognition of inherent risk factors can help practitioners make sound clinical decisions when extrinsic risk factors can inhibit safe participation. Extrinsic risk factors include exercising in warm or hot, humid environmental conditions; wearing protective equipment; having inappropriate work-to-rest ratios; or having insufficient access to water and shade.[2] The intrinsic risk factors for EHI include history of EHI; poor cardiovascular and physical fitness (and accompanying obesity); inadequate heat acclimatization; dehydration or electrolyte imbalance; recent febrile illness; sleep deprivation; a "never give up" or "warrior" mentality; a high level of motivation or zealousness; and use of questionable drugs, herbs, or supplements.[3,4] These intrinsic risk factors of EHI can be identified during the PPE, but most examinations are inadequate to obtain enough information to identify individuals at risk. Current research supports extending the length of the PPE to include more indicators for cardiovascular, respiratory, and general medical conditions, including EHI.[5–11] Expanding the PPE would allow practitioners to identify at-risk athletes and likely would prevent undue injury or illness. Using a preparticipation screening instrument to identify intrinsic risks for EHI would allow ATs to determine which individuals might be susceptible to heat illnesses.[8] Therefore, the purpose of our investigation was to determine content validity of a heat-illness screening instrument, the Heat Illness Index Score (HIIS), designed to be used by the AT as part of the PPE.

## METHODS

### Research Design

We used the Delphi panel technique to estimate content validity of the HIIS. The Delphi panel technique is a research design using several rounds (3–5) of communication among experts to establish consensus for the content.[12–19] The technique uses the opinions of expert panelists while maintaining anonymity among them.[12–19] This is the preferred technique for determining content validity because some researchers have suggested that focus groups and consensus conference techniques often force participants into consensus or that one or a few experts might dominate the consensus process.[17] Selection of panelists or experts has been questioned throughout the literature because of investigator bias[13]; however, choosing panelists who provide a balance of investment in the topic and impartiality helps to develop a qualified panel.[18] We used the Delphi panel technique to establish consensus on the content and quality of the HIIS instrument by sampling and interviewing individuals across diverse locations and with expertise in EHI.[17] Although we were not blinded to each panelist, we requested that they keep their participation confidential in an effort to maintain anonymity among panelists.

### Participants

We recruited potential panelists via telephone and provided a brief overview of the investigation. We selected a panel of 6 experts (5 researchers, 1 clinical AT) using the following criteria: certified AT; environmental illness researcher or team physician; publications (total = 236, mean = 39 ± 60) and presentations in scholarly journals or at clinical symposia related to environmental illness; advanced degree in the area of kinesiology, exercise physiology, or exercise science; and/or clinical experience with frequent exposure to the prevention, recognition, and treatment of EHI. Upon agreement to engage in the investigation, we scheduled individual semistructured interviews at the annual meeting of the National Athletic Trainers' Association in 2006 or by telephone. During the interview session, we explained the objectives, procedures, risks, and benefits of the study. Panelists provided written informed consent, and the institutional review board of Florida International University approved the study.

### Instruments

The HIIS instrument was developed as a screening tool to identify the 10 major risk factors for EHI as outlined in the "National Athletic Trainers' Association Position Statement: Exertional Heat Illnesses"[3] and the "Inter-Association Task Force on Exertional Heat Illness Consensus Statement"[4] (Table 1). The instrument was designed to be administered by an AT during the PPE using questions and clinical information available in the athletic training clinical setting. We created objective and measurable items and subitems from the intrinsic risk factors of EHI.[3,4] Each risk factor was attached to a 5-point Likert scale, with 0 indicating *lowest risk* and 4 indicating *highest risk*. The rating for the risk factor was summed at the end of the instrument. A rating of *high risk* was associated with a total score ranging from 30 to 44 or a score of 4 on 3 or more questions, a rating of *moderate risk* was associated with a total score ranging from 15 to 29, and a rating of *low risk* was associated with a total score ranging from 0 to 14. Areas to include additional descriptive information were also available for several items. In addition, we included the maximal oxygen consumption ($\dot{V}O_{2max}$) run test as a physiologic measure of overall fitness because it is strongly correlated with direct measurement of $\dot{V}O_{2max}$ on a treadmill.[20]

**Table 1. Preliminary Heat Illness Index Score Items (Before Round 1)**

| Item |
| --- |
| Previous history of exertional heat illness |
| Normal hours of sleep |
| Recent illness |
| Motivation during activity |
| Intensity and duration of recent training activity |
| Environmental conditions during recent training activity |
| Supplements or medications (dosages) |
| Baseline hydration (urine specific gravity) |
| Body mass index |
| Maximal oxygen consumption run test |

### Delphi Panel Procedures

The Delphi panel technique commonly uses 3 rounds of review but can use up to 5 rounds until consensus is achieved. Our investigation required 3 rounds of review.

**Round 1.** Although an interview is not a required procedure within the Delphi panel technique, some researchers have suggested that the personal effect of face-to-face initial contact with the researchers influences panelists to maintain participation through subsequent rounds.[15] Therefore, we conducted semistructured interview sessions with the participants. We allowed panelists time to review the instrument and then instructed each panelist to answer a series of questions (Table 2). Immediately after the interviews, data were transcribed and coded with the feedback used to revise the HIIS instrument. Approximately 2 weeks were required to analyze and organize round 1 data.

**Round 2.** In round 2, we sent panelists the revised instrument, a summary of data gathered in round 1, reference documents,[3,4] a detailed list of revisions, and a questionnaire. We instructed panelists to complete the questionnaire by marking their levels of agreement with an X on a visual analog scale (11.4 cm), with the extreme indicators of *strongly disagree* and *strongly agree*, for each of the 43 revisions. After providing feedback for the suggested revisions, we instructed the panelists to rate their overall agreement with each revised item and their overall agreement with the scoring criteria for each item. The panelists marked their levels of agreement with an X on the

Table 2. Semistructured Interview Questions Used in Round 1 of Delphi Panel Investigation

| Question |
|---|
| Do you believe the Heat Illness Index Score is a practical approach to identifying exertional heat illness during the preparticipation physical examinations? |
| Do you suggest we add items? If so, what are your suggestions? |
| In particular, do you suggest an item regarding the presence of sickle cell trait should be included? |
| Do you suggest we delete items? If so, which ones? |
| Do you suggest we revise any of the current items? If so, what revisions do you suggest? |
| Do you think the grading scale for each item is appropriate? If not, do you have suggestions for revision? |
| Do you think the scoring scale for the instrument is appropriate? If not, do you have suggestions for revision? |
| What is your overall opinion of the instrument? |
| What is your overall opinion of the instrument's intended application? |

visual analog scale. We analyzed the data using the mean and SD. We accepted revisions if the mean was greater than *agree* and the SD still permitted a positive response (≥midline). We also instructed the panelists to provide additional comments and suggestions if they did not agree with any of the items.

**Round 3.** In round 3, we sent panelists the revised HIIS and a detailed list of revisions with another questionnaire. Because we were approaching consensus, we instructed participants to rate their levels of agreement with each item and to rate their overall levels of agreement with the instrument on a 4-point Likert scale, with anchors of 1 (*strongly disagree*) and 4 (*strongly agree*). Participants also had space to provide additional comments or suggestions for the final instrument. We calculated the mean and SD for each question in the questionnaire. The HIIS items were accepted for the final instrument if panelists demonstrated consensus greater than or equal to 3. We calculated frequency of responses for the overall level of agreement with the instrument, and the HIIS was accepted if panelists demonstrated a consensus of responses greater than or equal to 3.

## RESULTS

### Round 1

In round 1, panelists supported the inclusion of 7 of the 10 questions in the instrument. Panelists supported the other 3 questions but requested revisions. We gathered the panelists' suggestions and revised the instrument accordingly.

### Round 2

Based upon the feedback from the panelists in the first round of interviews, we developed 43 revisions for the instrument. When we asked the panelists to rate their overall agreement with the 43 revisions, they rejected 7 (16.3%) and suggested further modification to 2 of the revisions. We used the panelists' quantitative and qualitative feedback from the questionnaire to further develop the instrument.

### Round 3

Because the means were greater than or equal to 3 (Table 3), all items were accepted in the HIIS. Furthermore, 100% of the panelists agreed (n = 3 of 6) or strongly agreed (n = 3 of 6) with the content of the final version of the instrument (Appendix).

## DISCUSSION

The purpose of our investigation was to determine content validity of a heat-illness screening instrument. We established content validity with 3 rounds of panelist consensus. We believe that the instrument requires further revision and implementation to establish diagnostic accuracy and clinical usefulness.

The risk factors associated with EHI are well established in the literature, and the development of a screening instrument is a logical step toward identifying individuals at inherent risk of EHI. Recently, Cooper et al[21] investigated the presence of heat illness at 5 southeastern US universities. In addition to gathering environmental-condition data, the researchers also instructed ATs to report the occurrence of EHI throughout 3 months of football training and competition.[21] They found 139 EHIs, which primarily included heat cramps, heat exhaustion, and heat syncope, were reported over approximately 33 000 exposures. Furthermore, professional position stands and consensus statements have identified the best methods for prevention, recognition, and treatment of EHI.[2–4] Prevention includes appropriately identifying at-risk athletes and educating athletes to reduce risk factors that they can control. Moreover, it is the role of the AT to restrict or modify participation when the risk is too great. Although we were unable to implement the instrument to identify its ability to attenuate these occurrences of heat illnesses, we believe we were able to establish the appropriate content to do so.

Screening instruments, particularly PPEs, have been used for more than 30 years to identify potentially harmful illnesses or conditions that might limit participation.[9] The

Table 3. Results of Round 3 of the Delphi Panel[a]

| Item | Mean | SD |
|---|---|---|
| 1. Previous history of heat illness | 3.67 | 0.52 |
| 2A. Normal hours of sleep | 3.50 | 0.84 |
| 2B. Sleep in air conditioning | 3.50 | 0.84 |
| 2C. Sleep less than usual | 3.50 | 0.55 |
| 3. Recent illness | 3.83 | 0.41 |
| 4. Motivation | 3.00 | 1.26 |
| 5. Intensity and duration of activity | 3.33 | 0.82 |
| 6. Environmental conditions | 3.83 | 0.41 |
| 7. Product consumption | 3.83 | 0.41 |
| 8. Baseline hydration level | 3.83 | 0.41 |
| 9. Body mass index | 3.67 | 0.52 |
| 10. Maximal oxygen consumption run test | 3.50 | 0.55 |

[a] The means and SDs are from the panelists' ratings of their levels of agreement with each item on a 4-point Likert scale with anchors of 1 (*strongly disagree*) and 4 (*strongly agree*).

**Table 4. Questions to Assess Intrinsic Risk Factors in the Preparticipation Physical Examination[a]**

| Risk Factor | How Identified |
|---|---|
| History of exertional heat illness | Ask: "Have you ever experienced exertional heat illness?" (Provide descriptions, if necessary.) If YES, ask: "What type and how many incidents?" |
| Poor physical fitness | Determine body mass index (body mass in kg/[height in m × height in m] = $kg \cdot m^{-2}$) or use body-composition test. |
| Poor cardiovascular fitness level | Determine maximal oxygen consumption run test (12-min walk/run), use graded exercise test, or use other test with norms for comparison. Patients MUST be cleared for participation by a physician. This test should be performed before the beginning of preseason practices. |
| Recent febrile illness (>101°F [38.3°C]) | Ask: "In the last week, have you had any illness with a fever (>101°F) or digestive problems, such as vomiting or diarrhea?" |
| Current hydration status | Measure urine specific gravity using clinical refractometer. |
| Insufficient heat acclimatization | Ask: "During your cardiovascular training, were you performing outdoors in hot or humid conditions?" |
| Poor nutrition or consumption of questionable supplements or medications | Ask: "What products (including medications, drugs, herbs, or supplements) do you consume?" (Use dosage or serving-size information to determine how much and how often these products are consumed.) |
| A "never give up" or "warrior" mentality | Ask: "When you practice or compete, what is your level of motivation?" (often unreliable) |
| Sleep deprivation or exposure to heat and humidity throughout night | Ask: "How many hours do you usually sleep on a daily basis?" Ask: "In the last week, how many nights did you get less than your normal amount of sleep?" Ask: "In the last week, how many nights did you sleep in a non–air-conditioned room?" |

[a] Adapted from Eberman LE, Cleary MA. Preparticipation physical exam to identify at-risk athletes for exertional heat illness. *Athl Ther Today.* 2009;14(4):4–7. © Human Kinetics Inc.

medical-history aspect of a PPE has the potential to identify almost 75% of the conditions that prohibit participation,[11,22] yet more and more conditions are causing concern and should be included.[11] The American Academy of Pediatrics considers a history of heat illness to be a potentially disqualifying condition and recommends individual evaluation to determine the risk for participation.[9,11] When we can reveal previous medical history of conditions, such as recurrent heat stroke or rhabdomyolysis, practitioners can make the appropriate adjustments to restrict or modify activity in extreme environmental conditions. These recommendations can be followed only when health care professionals are able to access this information before participation by using a valid screening instrument. Through the consensus of experts, we identified the appropriate criteria for expansion of the history-collecting capabilities of a PPE to include risk factors for EHI. Implementation will help to further evaluate the criteria and identify the variable importance of each risk factor in future investigations.

The identifiable risk factors for EHI, both intrinsic and extrinsic, should serve as a means of awareness for ATs responsible for preventing EHI. In this investigation, experts agreed that failure to train in warm or hot, humid environmental conditions while wearing protective equipment; having a history of EHI; poor cardiovascular and physical fitness (and accompanying obesity); dehydration, electrolyte imbalance, or inadequate heat acclimatization; recent febrile illness; sleep deprivation; a "never give up" or "warrior" mentality; a high level of motivation or zealousness; and using questionable drugs, herbs, or supplements were important data to collect via the HIIS. All criteria achieved a level of *agree* (Table 3), and the item with the most contention and variability concerned motivation (item 4). All panelists remarked (via the additional feedback sections on the questionnaires) that, although extremely crucial, this information would be difficult to measure objectively. These remarks likely accounted for the lower score and variability among the panelists on this item.

Although the general consensus supports the use of the PPE, evidence has suggested that the PPE does not effectively screen patients for a variety of preventable, catastrophic conditions.[23] We should work to establish accuracy (the ability to detect the target condition) and effectiveness (detection that improves the likelihood of favorable outcomes)[23] within these screening instruments. Future implementations of the HIIS should include a comparison group and rates of participation among all athletes screened that will allow us to determine sensitivity and false-negative rates (diagnostic accuracy). In addition, a linear regression model should be used to determine the predictive capabilities of each item because some items might not be necessary or might not have the same weight in the final score. Until the instrument can be implemented on a large scale to determine diagnostic accuracy, we suggest that practitioners include questions related to EHI on the typical PPE (Table 4)[24] to identify risk factors. Finally, an instrument that does not require implementation by an AT and can be completed by the athlete might be the most efficient means of screening athletes.

## CONCLUSIONS

We used a Delphi panel technique with the consensus of experts to estimate content validity of a heat-illness screening instrument, the HIIS. Future research is necessary to refine a user-friendly and effective instrument for screening athletes. Although a valid instrument is not finalized yet, we suggest that practitioners ask questions related to EHI risk factors during the PPE until an instrument with strong diagnostic accuracy is available. Furthermore, we invite feedback from those using the HIIS in clinical practice.

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**HEAT ILLNESS INDEX SCORE (HIIS) RISK ASSESSMENT**
*TO BE COMPLETED BY THE CERTIFIED ATHLETIC TRAINER*

**Participant/Athlete:** ____________________ **Date:** ________________ **Time:** ________________

**Site:** ____________________________________ **ATC:** _______________________________________

**Part 1. Exertional Heat Illness (EHI) Risk Factors**
**ATC INSTRUCTIONS:** Read each question to the athlete and record the presence of EHI risk factors.

1. A. Have you ever experienced Exertional Heat Illness (use attached descriptions if necessary)? NO / YES

   B. If YES, how many incidents? _____________
   (*Complete section below for most recent incident. For more than one incident, complete attached form*)

   C. How long ago was your most recent incident?______________ days / months / years (*Circle one*)
   What were your signs and symptoms? *Use attached Signs and Symptoms of EHI Table and Definitions of EHI to categorize this incident:*

   | | |
   |---|---|
   | Dehydration | Heat Cramps |
   | Heat Exhaustion | Heat Stroke |

   D. Who restricted you from activity? (*Please circle*)
   Physician / Certified Athletic Trainer / EMT or Paramedic / Parent / Coach / Self / Other ____________
   How long were you restricted from full activity? (*Check one*).
   Mild = part of a practice or less than 1 day restricted from activity
   Moderate = multiple practices or more than 1 day restricted from activity, and/or out-patient hospitalization ($\geq$1 day)
   Severe = in-patient hospitalization (>1 day)

   **Previous history of EHI Risk Factor** (*Circle highest*)
   0 No history of EHI
   1 One incident of Dehydration
   2 One or more incidents of Heat Cramps
   3 One or more incidents of Heat Exhaustion
   4 One or more incidents of Heat Stroke

2. A. How many hours do you usually sleep on a daily basis? ___________ hours

   B. In the last week, how many nights did you sleep in a **non-air conditioned** room?
   0 Once or less
   1 Twice
   2 Three times
   3 Four times
   4 More than four times per week

   C. In the last week, how many nights did you get **less than your normal** amount of sleep?
   0 Once or less
   1 Twice
   2 Three times
   3 Four times
   4 More than four times per week

3. In the last week, have you had any illness with a fever (>101°F) or digestive problems such as vomiting or diarrhea?
   0 No illness present
   1 Less than 1 day in duration
   2 Lasting about 2 days
   3 Lasting about 3 days
   4 More than 4 days in duration

4. When you compete, what is your level of motivation?
   0 None, I don't want to compete
   1 Motivated some of the time
   2 Motivated most of the time
   3 Highly motivated most of the time
   4 Highly motivated all the time

5. In the past 3 months, what was your **average** intensity and duration of your cardiovascular training? (*Circle highest*)
   0 Intense training more than 90 min/week
   1 Intense training 30 – 90 min/week
   2 Moderate training 30 – 90 min/week
   3 Light training more than 90 min/week
   4 No activity or Light training less than 90 min/week
   <u>Light</u> (6 – 11 on Borg scale) = Extremely light, or very light (easy walking slowly at a comfortable pace)
   <u>Moderate</u> (12 – 14 on Borg scale) = Somewhat hard (it is quite an effort; you feel tired but can continue)
   <u>Intense</u> (15 – 20 on Borg scale) = Heavy or very strenuous, and you are very fatigued, extremely hard (you can not continue for long at this pace), or maximal exertion

6. Of the cardiovascular training reported in question 5, what **percent of your training** was performed outdoors in the following conditions? (*Circle highest*)
   0 At least 75% of my training was outdoors between 10 am and 4 pm in Hot, Humid conditions
   1 50 - 74% of my training was outdoors between 10 am and 4 pm in Hot, Humid conditions
   2 Less than 49% of my training was outdoors between 10 am and 4 pm in Hot, Humid conditions
   3 50% or more of my training was outdoors before 10 am/after 4 pm in Hot Humid conditions or between 10 am and 4 pm in Warm, Dry conditions
   4 Less than 49% of my training was outdoors in Warm, Dry conditions or I train in Air Conditioning
   <u>Hot, Humid</u> = Greater than 85 °F and 68% relative humidity
   <u>Warm, Dry</u> = Between 70 and 84 °F and less than 68% relative humidity

**Training History:**
Training duration at current geographic location: _________ days / months / years (*circle one*)
Previous geographic location (City, ST): ____________________________________________
Training duration at previous geographic location: ________ days / months / years (*circle one*)

7. A. What products (including medications, drugs, herbs, or supplements) do you consume?
   □ cold medicine, anti-asthma, or anti-histamines
   □ anti-depressant medications
   □ Ritalin™ or other stimulants
   □ diuretics or "water pills"
   □ ephedra (ma huang, pseudoephedrine)
   □ creatine or amino acids
   □ Red Bull™ or other "energy drinks"
   □ Alcohol
   □ Other? *Be specific:* ______________________________________________________

Of the products identified above, how much/how often are these products consumed on a cumulative daily basis? *Specify the type/ brand/ amount consumed:*

B. Using dose or serving size recommended by manufacturer, identify cumulative amount consumed: (*Circle highest*)

0 Less than 1 dose or serving/day
1 About 2 doses or servings/day
2 About 3 doses or servings/day
3 About 4 doses or servings/day
4 Greater than 4 doses or servings/day

**Part 2. Resting Baseline Information**
**ATC INSTRUCTIONS:** Record the information and circle the number according to the following signs of Exertional Heat Illness

8. Baseline hydration level. *Measure urine specific gravity using clinical refractometer (preferably).*

Method used to determine USG (Circle one). Refractometer / Dip sticks / Other (*Specify*) ____________

**Athlete's baseline hydration level.** (*Circle one*)

0 Less than 1.014
1 Between 1.015 – 1.019
2 Between 1.020 – 1.024
3 Between 1.025 – 1.029
4 Greater than 1.030

9. Body Mass Index = (body mass in kg/height in cm x height in cm) x 10,000 = $kg{\bullet}cm^{-2}$

*Record the following:* Gender M / F Body mass ______kg Height ________cm Age ______yr

*Use the online calculator at:* http://www.halls.md/body-mass-index/av.htm *and record the following:*

BMI: _____________ and Percentile Rank _______________

**Athlete's Body Mass Index.** (*Circle one*)

0 Less than $25^{th}$ percentile
1 26-$40^{th}$ percentile
2 41-$60^{th}$ percentile
3 61-$84^{th}$ percentile
4 Greater than $85^{th}$ percentile

10. $VO_{2max}$ Run Test. Athletes MUST be cleared for participation by a physician. This task should be performed prior to the beginning of pre-season practices. After a warm up, have the athlete walk or run as fast a possible for exactly 12 minutes.

*Enter the distance s/he was able to reach in 12 minutes:* ___________ m.
*Use the following calculation* (Distance covered in meters - 504.9) ÷ 44.73 *or the following online calculator to estimate the* $VO_{2max}$: http://www.brianmac.demon.co.uk/gentest.htm

Estimated $VO_{2max}$: ___________ ml/kg/min

**Athlete's estimated $VO_{2max}$.** (*Circle one*)
0 Superior > 52.4
1 Excellent 46.5-52.4
2 Good 42.5-46.4
3 Fair 36.5-42.4
4 Poor < 36.4

Reference: The Physical Fitness Specialist Certification Manual, The Cooper Institute for Aerobics Research, Dallas TX, revised 1997 printed in Advance Fitness Assessment & Exercise Prescription, 3rd Edition, Vivian H. Heyward, 1998.p48. (For Males 20-29 years old).

**IF INFORMATION IS AVAILABLE:** Has this athlete been tested for Sickle Cell Trait? YES / NO
If YES, what were the results? NEGATIVE / POSITIVE (*circle one*)
Is this self-report data from athlete? YES / NO (*circle one*)

**Part 3. Assessment of Exertional Heat Illness (EHI) Risk Factors**
**ATC INSTRUCTIONS:** Add the points for each question to determine this athlete's risk of EHI.

**Total Score:** ___________________

**Number of Questions scoring 4** ___________

| Total Score | Risk | Recommendations for Exercise in Hot, Humid Environments |
|---|---|---|
| **30 – 44** or score of 4 on 3 or more questions | **High** | This athlete is a cause for concern. Reduce intensity and duration of exercise in Hot, Humid Environments and monitor this athlete closely. Strictly follow established guidelines for provision of ample fluids and rest in the shade. |
| **15 – 29** | **Moderate** | There is less of a concern for this athlete; however, risk exists. Follow recommended guidelines for work:rest ratios and provide ample fluids and rest in the shade. |
| **0 – 14** | **Low** | This athlete is least at risk; however, risk exists. Provide ample fluids and rest in the shade according to established guidelines. |

**This Athlete's risk of EHI:** HIGH MODERATE LOW (*circle one*).

**Appendix. Final Heat Illness Screening Instrument**

Abbreviations: ATC, certified athletic trainer; EMT, emergency medical technician; USG, urine specific gravity; $\dot{V}O_{2max}$, maximal oxygen consumption.
Reference for Borg scale: Borg.[25]
Manufacturers: Ritalin (Novartis International AG, Basel, Switzerland); Red Bull (Red Bull North America, Santa Monica, CA).

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*original research*

# Work–Family Conflict Among Athletic Trainers in the Secondary School Setting

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***Context:*** Work–family conflict (WFC) negatively affects a professional's ability to function at work or home.

***Objective:*** To examine perceptions of and contributing factors to WFC among secondary school athletic trainers.

***Design:*** Sequential explanatory mixed-methods study.

***Setting:*** Secondary school.

***Patients or Other Participants:*** From a random sample of 1325 individuals selected from the National Athletic Trainers' Association Member Services database, 415 individuals (203 women, 212 men; age = 36.8 ± 9.3 years) provided usable online survey data. Fourteen individuals participated in follow-up interviews.

***Intervention(s):*** Online WFC questionnaire followed by in-depth phone interviews.

***Main Outcome Measure(s):*** Descriptive statistics were obtained to examine perceived WFC. Pearson product moment correlations were calculated to examine the relationship between work hours, total athletic training staff, and number of children and WFC score. We performed analysis of variance to examine differences between the independent variables of sex and control over work schedule and the dependent variable of WFC score. The a priori $\alpha$ was set at $P \leq .05$. Qualitative data were analyzed using inductive content analysis. Multiple-analyst triangulation and member checks established trustworthiness of the qualitative data.

***Results:*** Mean WFC scores were 23.97 ± 7.78 for scale 1 (*family* defined as having a partner or spouse with or without children) and 23.17 ± 7.69 for scale 2 (*family* defined as individuals, including parents, siblings, grandparents, and any other close relatives, involved in one's life), indicating moderate perceived WFC. A significant relationship was found between the average hours of work per week and WFC scores: those with less scheduling control experienced more WFC. Two dimensions emerged from the qualitative methods that relate to how WFC is mitigated in the secondary school environment: (1) organizational—having colleagues and administration that understood the role demands and allowed for modifications in schedule and personal time and (2) personal—taking time for oneself and having a family that understands the work demands of an athletic trainer resulted in reduced perceived WFC.

***Conclusions:*** A large number of work hours per week and lack of control over work schedules affected the perceived level of WFC.

***Key Words:*** work–family interface, work–family balance, role conflict

**Key Points**

- Work–family conflict is experienced by athletic trainers in the secondary school setting, regardless of sex, family situation, or the number of children.
- Organizational support from administrators and coaches was perceived to help balance work and family obligations.
- Taking time for oneself and having a family that understands the athletic trainer's work demands also reduced work–family conflict.

Work–family balance has been documented in the literature[1–3] to be an important retention factor for those individuals employed in the sport industry (eg, coaches, athletic trainers [ATs]). Capel[1] reported the lack of personal and family time as a reason to leave the athletic training profession, a concern echoed by the findings of a Women in Athletic Training Committee survey.[4] In examining retention factors among collegiate coaches and administrators, Pastore et al[2] noted that they were more likely to remain in their current positions as a result of the fulfillment of work–family balance. Although the work–family interface has become increasingly popular among scholars, until recently, limited attention has been given to the construct for those professionals working within the sport industry.[5–7]

Researchers have begun to examine work–family conflict (WFC) within the coaching profession[5–7]; however, there is a modest amount of WFC within the athletic training profession.[8–11] Furthermore, the occurrence of WFC has only been examined within the collegiate setting,[8–11] and the findings may not be transferable to all clinical settings. At the initiation of this study (March 2009), 14.5% of all National Athletic Trainers' Association (NATA) members provided athletic training services to secondary schools either directly or through outreach programs, making it one of the larger clinical settings for employment.[12] Additionally, the American Medical Association[13] and the NATA[14,15] have developed official and summary statements, respectively, that encourage all schools with sporting programs, including secondary schools, to have adequate athletic medical personnel (full-time ATs) on staff. Moreover, with states such as New Jersey promoting legislation to mandate onsite medical coverage by an AT, the number of ATs working in that clinical setting will only increase.[13–15] Thus, investigating issues such as WFC that can negatively affect the professional role is warranted in the secondary school setting.

Long work hours have been documented as a primary contributing factor to the occurrence of WFC within several professions,[16,17] including coaching[6] and athletic training.[8–10] Other factors, such as control over work schedules[8,9] and flexibility in work schedules,[5,7–9] have been identified as mediators for individuals managing their professional and personal lives. The work–family interface is complex, and scholars[5,6] have suggested that it must be examined via a multilevel framework that includes organizational factors (eg, work hours, scheduling), individual factors (eg, personality, values), and sociocultural factors (eg, society views, gender roles). The purpose of our study, therefore, was twofold. First, we sought to explore the existence of WFC among ATs working in the secondary school setting and to identify those factors that contribute to their WFC in this setting. Second, we wanted to gain insight and understanding as to those factors that mitigate WFC in the secondary school setting. The following questions guided our investigation:

1. To what extent do ATs in the high school setting perceive WFC?
2. Is there a connection between the level of WFC and various demographic variables (eg, sex, marital status, family-unit size)?
3. Does the high school work environment influence the occurrence of WFC?
4. What factors are perceived to mitigate the occurrence of WFC?

## METHODS

A sequential, explanatory, mixed-methods design[18] with 2 phases was used for this study. This design allows the researchers to collect and analyze data quantitatively and then follow up with qualitative information to not only gain additional insight but also to confirm or disconfirm the study's findings.[18] Phase I involved a cross-sectional survey of ATs in the secondary school setting to quantify their perceptions of WFC. Phase II involved collecting qualitative data from a purposeful sample of participants who completed phase I and served as a means to both confirm the phase I findings and investigate how ATs at the secondary level manage responsibilities in both their personal and professional lives. The study received institutional review board approval from Northern Illinois University and the University of Connecticut before data collection began.

### Participants and Procedures

Phase I consisted of an online survey. The NATA Member Services Department provided a randomized list of 1325 e-mail addresses of secondary school NATA members whose primary work setting was secondary school; 1303 e-mails were deliverable. An initial e-mail invitation containing the survey Internet link was sent to these individuals. A total of 440 ATs (33.7%) volunteered to participate and accessed the online survey; of these, 415 surveys were usable for data analysis.

**Table 1. Participants' Demographic Data (N = 415)**

| Demographic Characteristic | n (%) |
|---|---|
| Sex | |
| Female | 203 (48.9) |
| Male | 212 (51.1) |
| Highest degree obtained | |
| Bachelor's | 160 (38.6) |
| Master's | 248 (59.8) |
| Doctorate | 4 (0.9) |
| Not specified | 3 (0.7) |
| Current job situation | |
| Full time | 338 (81.4) |
| Part time | 62 (14.9) |
| Clinical outreach | 11 (2.7) |
| Not specified | 4 (1.0) |
| Family situation | |
| Married or partnered | 270 (65.1) |
| Single, never married or partnered | 90 (21.7) |
| Living with significant other | 34 (8.2) |
| Divorced | 16 (3.9) |
| Not specified | 5 (1.1) |
| Children? | |
| Yes | 231 (55.7) |
| No | 183 (44.1) |
| Not specified | 1 (0.2) |
| National Athletic Trainers' Association District | |
| 1 | 30 (7.2) |
| 2 | 86 (20.7) |
| 3 | 59 (14.2) |
| 4 | 60 (14.5) |
| 5 | 20 (4.8) |
| 6 | 46 (11.1) |
| 7 | 35 (8.4) |
| 8 | 30 (7.2) |
| 9 | 27 (6.5) |
| 10 | 18 (4.3) |
| Not specified | 4 (1.0) |

At the conclusion of the WFC survey, interested individuals were invited to participate in phase II of the study, which involved confidential telephone interviews related to experience with WFC. Participants interested in the qualitative aspect of the study were instructed to provide confidential contact information (phone number and preferred time of day to be reached) to members of the research team. Because more individuals were interested in phase II than could be included, participants were randomly selected; we used data saturation to guide the total number of participants. Selected individuals were contacted with a consent form; once we received the consent form, we scheduled a formal interview and conducted it using a semistructured interview guide (Appendix). Table 1 provides a breakdown of the participants' demographic data.

### Instrumentation

The online survey consisted of 2 sections. The first section contained 15 items pertaining to general demographic characteristics such as age, sex, years of experience, hours worked, and marital status. The second section contained two 5-item scales evaluating one's perceived level

**Table 2. Work–Family Conflict Measures[a]**

| | Scale 1 | | Scale 2 | |
|---|---|---|---|---|
| | n | Mean ± SD | n | Mean |
| The demands of my work interfere with my personal and family life | 337 | 4.88 ± 1.70 | 411 | 4.82 ± 1.66 |
| The amount of time my job requires makes it difficult to fulfill my family responsibilities | 337 | 4.51 ± 1.68 | 411 | 4.33 ± 1.66 |
| Things I want to do at home do not get done because of the demands of my job | 337 | 4.72 ± 1.73 | 411 | 4.63 ± 1.81 |
| Due to work related duties, I have to make changes to my plans for family activities or miss out on family-related activities | 337 | 5.15 ± 1.66 | 411 | 5.14 ± 1.65 |
| There is a conflict between my job and commitment to those responsibilities and the responsibilities I have to my family | 337 | 4.67 ± 1.69 | 411 | 4.35 ± 1.72 |

[a] Scale 1 defined *family* as having a partner or spouse with or without children. Scale 2 defined *family* as those individuals, including parents, siblings, grandparents, and any other close relatives, involved in one's life. Individuals could answer either scale or both scales, depending upon their current family situation. Each instrument was a 7-point Likert scale with 1 = *strongly disagree* through 7 = *strongly agree*.

of WFC based upon current family status. Scale 1 defined *family* as having a partner or spouse with or without children; scale 2 defined *family* as those individuals, including parents, siblings, grandparents, and any other close relatives, involved in one's life. Participants had the option to answer one scale or both scales, depending upon their family situation.

The survey, which was developed and validated by Netemeyer et al[19] and Mazerolle et al[10] in separate population groups, is scored along a 7-point Likert scale ranging from 1 (*strongly disagree*) to 7 (*strongly agree*). The 5 WFC items (Table 2) have previously demonstrated adequate internal consistency with a Cronbach $\alpha$ of 0.88 for working professionals[19] and of 0.89 for ATs.[10] Each 5-item scale was summed to provide a measure of WFC. With the current data, our verification of the instrument's reliability revealed a Cronbach $\alpha$ of 0.954 for scale 1 (*family* defined as having a partner or spouse with or without children) and 0.937 for scale 2 (*family* defined as those individuals, including parents, siblings, grandparents, and any other close relatives, involved in one's life).

The semistructured interview guide was based on the study's purpose and research questions, as well as preexisting literature on WFC in the athletic training profession[8–11] and sport industry.[5–7] All of the questions were constructed using the open-ended format to encourage reflection and discussion regarding the participant's experiences. We selected the semistructured format because it provided methodologic rigor but also allowed us flexibility in the event an unexpected theme emerged from data collection.[20,21] Furthermore, when more than one researcher is involved in data collection, a semistructured interview format allows for consistency in collection methods as well as the production of reliable data.[22] Before data collection, the interview guide was shared with 2 social science researchers to ensure the questions were appropriate and reflected our study's purpose. Feedback was digested by the researchers, and changes and edits were made to enhance the clarity and flow of the interview guide.

## Data Analysis

We analyzed our quantitative data using SPSS (version 16.0; SPSS Inc, Chicago, IL). Participants' demographic data were analyzed with descriptive statistics, including means, SDs, frequencies, and percentages. Level of WFC was examined with descriptive statistics, specifically mean responses to each question and the corresponding SD. The summed response to the 5 WFC items in each scale provides a measure of the extent to which WFC permeated the work–home interface of the ATs.

To examine the relationship between the level of WFC and the demographic variables of average work hours per week, total number of athletic training staff in work context, and number of children in one's care, we conducted a Pearson product moment correlation, with the a priori $\alpha$ level set at $P \leq .05$. An analysis of variance with the $\alpha$ level set a priori at $P \leq .05$ was conducted to examine whether a difference existed between the independent variables of control over work schedule, sex, having children, and having a flexible work schedule and the dependent variable of WFC score.

The qualitative data obtained in phase II were analyzed using an inductive content analysis, paralleling the basic, or generic, approach described by Merriam.[20] The process involves first examining the content of the interview transcripts and identifying concepts related to the research questions and purpose. These concepts were tagged with a conceptual label to capture their meaning. The conceptual labels, or codes, were then examined and thematized. Once emergent themes were generated from the data, each theme was compared and contrasted for the purposes of identifying whether higher-order and lower-order themes were evident. Trustworthiness of the qualitative findings was established using member checks and multiple-analyst triangulation, 2 strategies that are effective in establishing trustworthiness when combined.[23] Member checks, a critical step for establishing credibility,[20] were performed using interpretative verification.[23] Seven randomly selected participants were invited to examine the qualitative research findings and to verify that the findings were reasonable based on the information provided in the interviews. Of the 7 individuals invited, 6 responded and verified the qualitative results. Two researchers independently followed the aforementioned steps in data analysis to ensure that the results were interpreted accurately (multiple-analyst triangulation).[23] The researchers discussed findings and agreed upon the final themes before sharing the results with the participants.

## RESULTS

Of the respondents, 203 (48.9%) were women and 212 (51.1%) were men. The participants were 37 ± 9 years old

Table 3. Interview Participants' Demographic Information

| Participant Pseudonym | Age, y | Sex | Years as Athletic Trainer | Years in Current Position | National Athletic Trainers' Association District | Highest Degree Earned | Family Situation | Employment Situation |
|---|---|---|---|---|---|---|---|---|
| Alisha | 40 | Female | 13 | 15 | 1 | Bachelor's | Married or partnered | Full time |
| Carmine[a] | 42 | Female | 21 | 20 | 2 | Bachelor's | Divorced | Full time |
| Jonathan | 50 | Male | 26 | 27 | 2 | Master's | Married or partnered | Full time |
| Julie[a] | 30 | Female | 8 | 6 | 2 | Bachelor's | Single | Full time |
| Hanna | 26 | Female | 3 | 2 | 4 | Master's | Married or partnered | Full time |
| Lanna | 41 | Female | 18 | 13 | 4 | Bachelor's | Married or partnered | Clinic-outreach |
| Phillip | 52 | Male | 30 | 24 | 4 | Bachelor's | Married or partnered | Full time[b] |
| Bill[a] | 38 | Male | 13 | 9 | 4 | Master's | Married or partnered | Full time[b] |
| Jocelyn | 37 | Female | 16 | 4 | 4 | Bachelor's | Married or partnered | Full time |
| Forest[a] | 41 | Male | 14 | 11 | 6 | Master's | Married or partnered | Full time |
| Raymond[a] | 49 | Male | 20 | 2 | 7 | Masters | Married or partnered | Full time |
| Kevin | 33 | Male | 6 | 4 | 9 | Master's | Married or partnered | Part time |
| Jayna[a] | 28 | Female | 8 | 6 | 10 | Master's | Single | Full time |
| Jan | 28 | Female | 6 | 3 | 10 | Bachelor's | Married or partnered | Full time[c] |

[a] Participated in the member-check process.
[b] Full-time teacher with athletic training responsibilities.
[c] Full-time instructor with no current athletic training responsibilities.

with 13 ± 8 years of experience as ATs. The majority (60%, n = 248) had obtained a master's degree.

Those ATs with children comprised 231 (55.7%) of the participants in the study. Additional demographic information for those participants in phase I of our study can be found in Table 1. A total of 14 individuals (8 women, 6 men) participated in phase II of the study. Participants in phase II averaged 38 ± 9 years of age with 14 ± 8 years of experience as ATs. Comparable with phase I, 3 (21.4%) of the participants were single and 6 (42.8%) had master's degrees.

Mean WFC scores were 23.97 ± 7.78 for scale 1 (*family* defined as having a partner or spouse with or without children) and 23.17 ± 7.69 for scale 2 (*family* defined as those individuals, including parents, siblings, grandparents, and any other close relatives, involved in one's life), indicating a moderate level of WFC (Table 2). The most highly rated items in both scales were "The demands of my work interfere with my personal and family life" and "Due to work related duties, I have to make changes to my plans for family activities or miss out on family related activities."

For scale 1, female participants' WFC scores were slightly lower (23.59 ± 7.69) than those of the males (24.25 ± 7.85). For scale 2, female participants' WFC scores were also slightly lower (22.67 ± 7.52) than those of the males (23.63 ± 7.82). However, we found no difference between males' and females' perceived level of WFC for either scale 1 ($F_{1,336}$ = .610, $P$ = .435) or scale 2 ($F_{1,410}$ = 1.6, $P$ = .207).

When comparing ATs with children to those without children, we identified no difference in either the scale 1 WFC scores ($F_{1,335}$ = 3.304, $P$ = .07) or the scale 2 WFC scores ($F_{1,408}$ = 1.753, $P$ = .186). Those with children, however, had slightly higher mean WFC scores for scale 1 (24.5 ± 7.7) than did those without children (22.91 ± 7.8). Similarly, those with children had slightly higher mean WFC scores for scale 2 (23.6 ± 7.71) than did those without children (22.58 ± 7.66).

We noted no difference in the scale 1 WFC scores ($F_{3,328}$ = .328, $P$ = .805) or the scale 2 WFC scores ($F_{3,402}$ = 1.11, $P$ = .345) among the various family situations (married or partnered; single, never married or partnered; living with significant other; divorced; not specified). Our correlation analysis revealed a weak positive relationship ($r$ = 0.10) between number of children and level of WFC on scale 1 that approached significance ($P$ = .065); the scale 2 correlation, however, was substantially weaker ($r$ = 0.079).

An examination of scheduling flexibility revealed a difference ($F_{2,335}$ = 13.47, $P \leq .01$) in scale 1 WFC scores. The Scheffe post hoc analysis demonstrated that those who always had scheduling flexibility had lower WFC scores (19.51) than did those who sometimes had scheduling flexibility (23.78) and those who never had scheduling flexibility (27.79). We also found a relationship between the average work hours per week and WFC scores on scale 1 ($r$ = 0.294, $P$ = .01) and scale 2 ($r$ = 0.311, $P$ = .01). Participants in phase I reported averaging 47.14 ± 14.3 hours of work per week.

Demographic information for those who participated in phase II, which involved in-depth interviews, is provided in Table 3. Our qualitative analysis revealed that managing WFC and balancing one's work life and personal life was associated with both organizational and personal dimensions (Figure). The following discussion describes each emergent dimension and its themes. Quotes are provided to support our findings, and pseudonyms are used to protect participant identity.

## Organizational Dimensions

The organizational dimensions theme explains the relationship between fulfillment of work–life balance through the workplace or organizational policies (or both). This dimension is summarized by interpersonal support from administration, fellow ATs in the work setting (if more than one), and coaches. The interpersonal support from these groups allowed for scheduling flexibility,

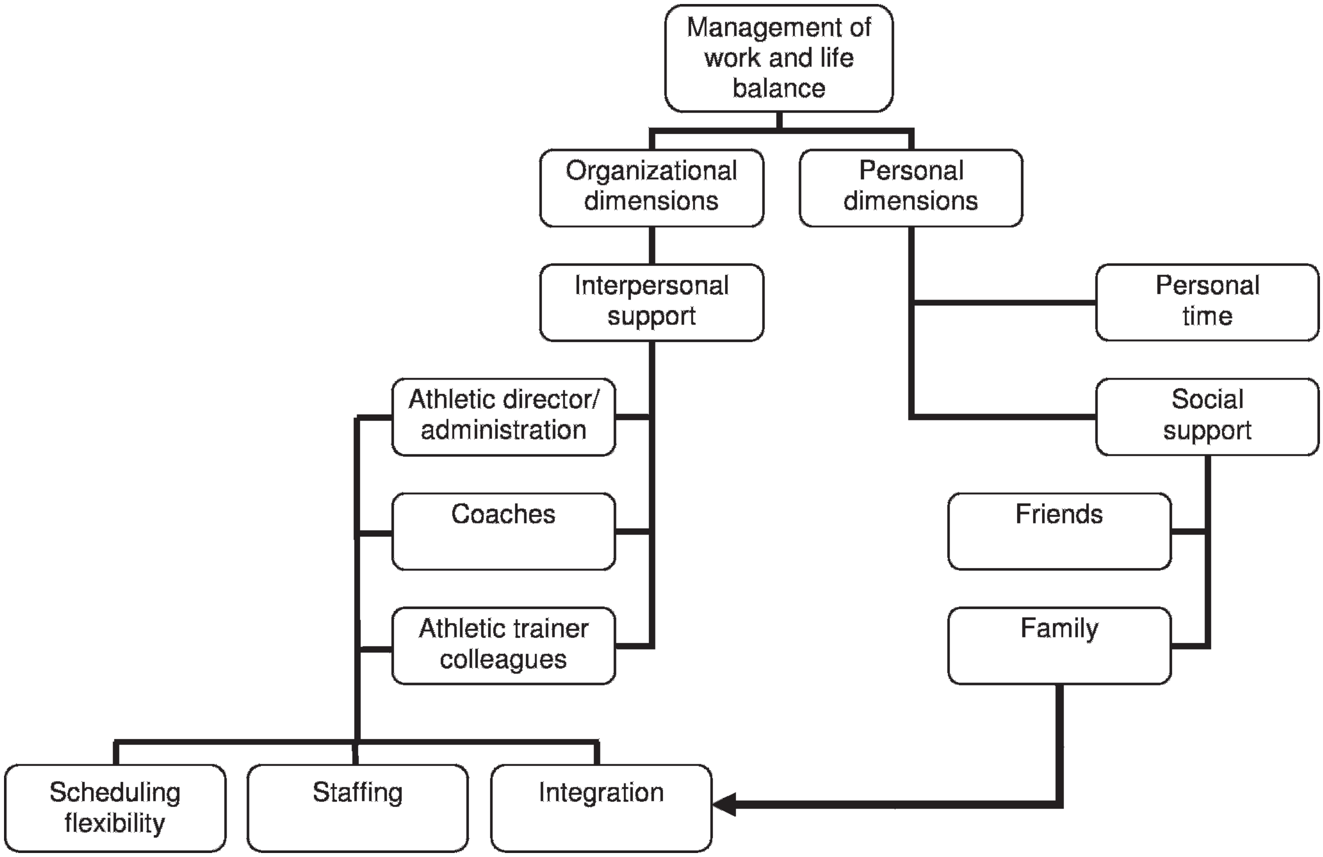


**Figure. Work–life balance for athletic trainers in the secondary school setting.**

staffing, and integration of personal-work life. In the following section, we present each factor that encompasses the organizational aspect of work–life balance.

**Support from Administrators and Coaches.** Having a supportive athletic director helped the participants to balance work and personal responsibilities. For example, Carmine stated:

> I would say personally, I'm very lucky with my athletic director, [he is] very supportive … [he] wants everything covered obviously …. if it comes to be that we both have, you know, personal issues and we can't be at something he's okay with that … he understands we both have families, and he's very flexible with it. I've seen other administrators in the area who are … expecting a lot more hours … they want to let [the teams] practice at night, and expect the trainer *(sic)* to be there at night while they decide to practice. Like I said, we've been very lucky with that.

Similarly, Julie corroborated this finding when she said, "my athletic director, who is my direct supervisor, is really understanding about if I need to take a sick day or a personal day as long as 1 of the 2 of us [ATs] can arrange coverage; he's fine with that, he's very supportive of that."

Administrator support was very important to a majority of the participants in phase II, but just as important were support and understanding from the coaching staff, particularly because they set practice and game schedules. Lanna commented on how understanding and support was garnered from both coaches and the athletic director when she said, "… most coaches at the high school have their own families so they tend to be a little more sympathetic. I have a really great athletic director and so when I would come to him, he was pretty sympathetic about needing some time here or there …."

Support from administration and coaches facilitated the use of several strategies by ATs to manage WFC. These strategies involved staffing and scheduling flexibility and family integration into the work context.

**Scheduling Flexibility and Staffing.** A level of flexibility with their schedules in the high school setting allowed participants to gain some balance between work life and family life. This flexibility was garnered in 2 major ways in the secondary school setting: (1) atmosphere and mindset of the setting and (2) number of staff members. Jayna discussed how she was able to work with her athletic director and modify her schedule to have personal time a couple of mornings a week, which speaks to both the aforementioned theme and the atmosphere of the secondary school setting:

> Mondays and Fridays, I don't work in the morning so I have those times for myself … sometimes I'll go in a little bit earlier and … work out … for myself and get some stuff done so I'm ready to go; school's over at 2:30 so I have to be kind of ready to go by 2:00.

The flexibility found in scheduling at the secondary school level, as a result of the atmosphere, was echoed by Bill when he stated, "I like the fact that at the high school level … I seem to have some control over my hours still, although not as much as I like to at times, but I still can have pretty flexible hours if I need."

For those participants with a second team member, work scheduling flexibility was improved and more realistic than for those without an additional staff member. Carmine discussed the improvements in his life balance when his administration added a second AT:

> Oh, it's night and day; it's amazing! I mean, having done it all [myself] for about 12 years and being the sole provider and trying to be everything to these athletes because they're so used to it—you know, to be at every event and be there every single day, well or sick …. The difference of hiring a second person and having that [scheduling] option is you know, like, irreplaceable. You know with my kids, now, if one of our kids is sick, he has kids as well, you know, we call each other, we don't have to call anybody else, you know, we call each other and say "Look, so and so is sick; I can't be in today," or "I'm going to be late," or "I need to, you know, chaperone this," or "go to the doctor," or, you know, so yah, it's been amazing. It's a huge difference.

Another participant, Forest, discussed the level of scheduling flexibility that comes with having additional staff versus working in isolation. He articulated that this "is my first time to have an assistant and it's been kind of neat to be able to walk away and say, hey I want to go do this and you got it. So for the last 2 years, it's been that way …."

**Family Integration.** The concept of family integration was mainly discussed by ATs with families and was defined for this group as the opportunity to incorporate family time into the workday. When supported by administration and coaches, ATs can bring family members, such as children, to practice or game coverage and interact with and care for them. For example, Jonathan stated, "when my kids were in elementary school, they literally walked from their elementary school 5 blocks to [my school] and spent the afternoon in the [athletic] training room. If they got their homework done quickly enough, they were able to go out and sit and watch games [with me]."

Family integration into the work context required support not only from administration and coaches but also from the family. Forest explained how his wife was instrumental in transporting his children to the school to be with him: "My wife is very supportive of me. I get my kids up here for, like, pregame meal before football games or basketball games or [they] come see me and we'll eat dinner together before I go back to work …."

### Personal Dimensions

Personal dimensions refer to those factors that allowed the secondary school AT to meet personal interests and obligations that were not dependent on or provided within the workplace. These factors included making time during the day for personal responsibilities and social support from both family and friends.

**Address Personal Time.** Participants explained that to balance work life and family life, you must be sure to address personal needs by ensuring you have time for yourself. When asked what advice she would give to those working in the secondary school setting to lessen WFC, Jayna stated: "You have to learn to say no. You can't be [at the school] all the time. Now, when we have days off I'm not there all the time … you just have to say 'no' and you have to kind of watch out for yourself because not everybody will." Jocelyn supported this by saying "… take time out for yourself because, when I first got started, it was just all about athletic training and then, now I realized if you have the time off you may as well take it because it's meant for yourself to have that."

**Social Support.** Obtaining social support from both family and friends was a key factor in balancing work and personal time. For example, Jocelyn explained how her husband helps to manage caregiving at home when she is busy with her role: "he just kind of picks up the slack during football so whatever I don't get done, he just kind of picks up and does it." Raymond explained how he received support from his wife to balance home responsibilities: "I wouldn't be able to [balance work and home life] without her. She runs the work in the house, she takes care of the details, she just tells me when to show up—and I do."

Social support was not only related to helping and/or covering specific family roles but also to obtaining a level of understanding from one's spouse or partner. For example, when asked how he was able to balance work and family life, Forest explained that it comes from a high level of understanding of the profession that his wife has:

> I think [for] most of it my work comes first, and my wife is very understanding of that. She's been very supportive. I mean she gets frustrated at times, but she's been with me since in high school, so I mean she's been around athletic training from the get go and she understands the hours and understands that we're not going to get paid a whole lot, but we're going to be okay, but she's been very supportive of what I do.

Friends also provided social support and understanding to ATs in this study. For example, Julie stated "… my friends are pretty understanding and because I don't have to come in to work until usually between 11:00 and 12:00, sometimes we get together for breakfast or an early lunch … or if I'm not working in an evening, we might get together then."

## DISCUSSION

The purpose of our study was to gain a better understanding of WFC within the secondary school setting. Specifically, we hoped to discover what factors, if any, lead to WFC for this group and what, if anything, can be done to improve life balance for the secondary school AT. Overall, we found that, as is the case for ATs in the collegiate setting, WFC can occur, but through support networks, which encompass work and home, a balanced lifestyle is feasible for the secondary school AT.

Regardless of sex, family situation, or number of children, participants in the current study experienced moderate levels of WFC. These results corroborate previous WFC research[8] that found that ATs working in the National Collegiate Athletic Association Division I setting experienced WFC regardless of sex or family status.

However, this finding was not substantiated by previous studies[24,25] on other working professionals. Those working professionals, particularly women with young children, experienced more WFC,[24,25] yet for our group of ATs, those demographic factors were not an influence.

A multitude of factors could explain this finding, but the most logical centers on the age of the data. Much of the sex and family status data were collected in the 1990s and may not fully illustrate the current dynamic in the workplace or at home. Furthermore, the customary roles of breadwinner and homemaker are no longer associated with traditional gender roles; many males are beginning to assume more of a role in household duties, thus possibly explaining the lack of gender differences.[26]

The ATs in the current study who had more control over their work schedules reported less WFC than did those without that degree of control; this finding was verified by the qualitative data analysis. This result also authenticates the work of previous researchers,[8] who noted that lack of scheduling flexibility and control over work schedule were contributing factors to WFC among both ATs and coaches working in the Division I setting.[5–7] Distinct, however, from the collegiate setting, the secondary school setting appears to provide the AT with more flexibility and control. On many occasions, the phase II participants indicated that the flexibility afforded by the secondary school setting allowed them to meet personal and family responsibilities when necessary. This is consistent with organizational research[7,10,27] demonstrating that providing flexible time to working professionals reduced experiences of WFC.

Mazerolle et al[8] also found that the hours worked to address job responsibilities were an antecedent of WFC. Similarly, we identified a positive relationship between the hours worked per week and WFC scores. Hours per week addressing athletic training obligations was a key qualitative finding related to role conflict in a study[28] examining role strain among dual-position ATs and physical educators in the secondary school setting. Moreover, Pitney et al[28] found that hours worked per week in athletic training was the only predictor of total role strain. In a separate study investigating the professional commitment of the AT, Pitney[29] showed that secondary school ATs took time to rejuvenate or handle the hours worked and made sure to take time away from their work-related responsibilities, indicating that hours worked had the potential to affect the ATs' quality of life or commitment to their positions.

The current study revealed how various aspects of the secondary school organization can mitigate perceived WFC. Participants explained that perceived support from administration and coaches was critical in balancing their work-related responsibilities and their personal lives. In most instances, the balance was achieved by modifying the work schedule, integrating family into the work context, or addressing staffing issues. In the sport context, Dixon and Sagas[7] found that organizational support reduced WFC. Similarly, ATs working in the secondary school setting who had support from administration tended to have less perceived role strain.[28] Participants in phase II of our study identified the support they received from the administration and coaches as rather "family friendly," meaning that the ATs could integrate their families into the work setting and take time to address personal needs that arose. In a recent work–life balance study, Mazerolle[30] identified integration as a strategy used by ATs working in the collegiate setting; integration has been suggested previously not only for the collegiate setting[10,31] but also for other working professionals as a means by which to reduce WFC.[26] These findings underscore the importance of an organizational support structure that values family-friendly policies as a way to reduce WFC.

Our participants discussed the need to create or maintain personal time so that they could take care of themselves or their families, or both. Setting boundaries to carve out time for oneself to limit the consuming nature of a particular professional role has been implicated as an important aspect of maintaining professional commitment[29] and reducing role strain.[28] In a study of professional commitment among ATs working in the secondary school setting,[29] participants explained the necessity of having adequate time away from a role to care for oneself and emotionally recharge. Pitney et al[28] found that ATs who proactively worked with administrators and coaches to make clear what they had time to do tended to perceive less role strain. Setting boundaries and prioritizing roles and responsibilities are often recommended by work–life scholars and experts[32] and are easily accomplished by saying "no," calling on coworkers, and applying integration.[30] As in the collegiate setting, having a coworker (or several coworkers) with whom to share work responsibilities allowed the secondary school AT to achieve a balance and assume some control over the work schedule. Interestingly, however, the concept of integration, which has been previously recommended for the collegiate AT, took on a different meaning at the secondary school level. For the collegiate AT, integration meant taking the "down time" during the workday to exercise, do laundry, or spend time with a spouse. The secondary school level provided a more traditional family-friendly environment, allowing the AT to interact with his or her children while working. Regardless of the setting, establishing boundaries and priorities appears to allow the AT to achieve a balanced lifestyle.

## Implications, Limitations, and Future Directions

Our findings demonstrate that WFC is experienced by ATs in the secondary school setting, regardless of sex, family situation, or number of children. These results confirm previous WFC results among ATs. Organizational support from administrators and coaches was perceived to help ATs to balance work and family obligations, allowing for scheduling flexibility and coverage by other staff, as well as family integration into the secondary school context. Organizational leaders in the secondary school setting who wish to reduce WFC among their staffs should consider creating family-friendly policies and exploring their staff's perceptions of the level of support they receive. Additionally, considering the expansion of staff and allowing for scheduling flexibility are advised, as is monitoring the hours worked per week by ATs in the secondary school setting.

Athletic trainers in the secondary school setting are advised to further develop interpersonal skills in order to negotiate with administrators regarding modifications of schedules, personal time release, and family integration into the work setting in order to mitigate WFC.

Our study cannot be generalized to all athletic training settings. For those ATs working in a clinical outreach setting, the influences of WFC may be much different. Although we included some participants who were employed in the clinical outreach setting, our purpose was not to examine workplace differences or the influence of dual responsibilities. Future researchers should investigate differences among those ATs employed directly in the secondary school setting versus those employed in the clinical outreach setting.

A one-time, cross-sectional survey has its own limitations, in that we were not able to obtain a full understanding of WFC influences over the course of an individual's career or even over a 1-year period. Longitudinal research is warranted to further understand the influences that career progression and changes in family status have on perceived WFC.

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**Appendix. Interview Guide.**

1. Please provide some information about your professional career.
2. Have you ever worked in another clinical setting besides the high school setting? What is so appealing about the high school setting for you compared to other clinical settings?
3. Describe the balance between your personal life and your work life.
4. Have you experienced challenges finding a balance between your personal and professional life?
    - If so, share an instance when you have faced this challenge.
    - If not, what has allowed you to maintain this balance?
5. Discuss if working in the high school setting provides a suitable working environment to achieve a balance between your work and home life.
6. How does your administration (HS AD)/supervisors (clinic) help or hinder in finding a balance between work and home?

7. In what way have co-workers helped or hindered your ability to maintain life balance?
8. In what way has your spouse/partner helped or hindered your ability to maintain life balance?
9. How do you and your spouse/partner divide the labor/ home responsibilities?
10. If a new athletic trainer was just about to enter this work setting, what advice would you give him/her to help them maintain a balanced life?

Abbreviation: HS AD indicates high school athletic director.

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# Assessing Strategies to Manage Work and Life Balance of Athletic Trainers Working in the National Collegiate Athletic Association Division I Setting

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***Context:*** Certified athletic trainers (ATs) working at the National Collegiate Athletic Association Division I level experience challenges balancing their professional and personal lives. However, an understanding of the strategies ATs use to promote a balance between their professional and personal lives is lacking.

***Objective:*** To identify the strategies ATs employed in the Division I setting use to establish a balance between their professional and personal lives.

***Design:*** Qualitative investigation using inductive content analysis.

***Setting:*** Athletic trainers employed at Division I schools from 5 National Athletic Trainers' Association districts.

***Patients or Other Participants:*** A total of 28 (15 women, 13 men) ATs aged 35 ± 9 years volunteered for the study.

***Data Collection and Analysis:*** Asynchronous electronic interviews with follow-up phone interviews. Data were analyzed using inductive content analysis. Peer review, member checking, and data-source triangulation were conducted to establish trustworthiness.

***Results:*** Three higher-order themes emerged from the analysis. The initial theme, antecedents of work–family conflict, focused on the demands of the profession, flexibility of work schedules, and staffing patterns as contributing to work–life conflict for this group of ATs. The other 2 emergent higher-order themes, professional factors and personal factors, describe the components of a balanced lifestyle. The second-order theme of constructing the professional factors included both organizational policies and individual strategies, whereas the second-order theme of personal factors was separation of work and life and a supportive personal network.

***Conclusions:*** Long work hours, lack of control over work schedules, and unbalanced athlete-to-AT ratios can facilitate conflicts. However, as demonstrated by our results, several organizational and personal strategies can be helpful in creating a balanced lifestyle.

***Key Words:*** work–family conflict, organizational support, professional satisfaction

**Key Points**

- Although professional demands, inflexible work schedules, and inadequate staffing patterns can cause conflicts, work–life balance is achievable for athletic trainers at the Division I level.
- To promote work–life balance, administrators should encourage teamwork, and athletic trainers can set boundaries and priorities.
- A strong support system, both at work and at home, is the critical link that allows athletic trainers to balance their professional and personal lives.

Juggling the demands of a career and a personal life is a challenge confronted by many certified athletic trainers (ATs).[1–3] Recent organizational research suggests that working professionals, regardless of marital status, will experience conflicts between their professional and personal lives,[4,5] which is also true for those ATs working at the National Collegiate Athletic Association Division I level.[1,2] Decreased time for family and personal obligations and an inability to create a balance between work and home have been linked to attrition among working professionals in sports.[6–9] Furthermore, the successful fulfillment of work–family balance has been linked to increased levels of job and life satisfaction,[10] as well as reduced turnover for working professionals.[10,11] As a result, many corporations and organizations are implementing policies such as flexible work schedules, on-site day care, and family leave as ways to help employees find a balance between their work and home lives.[12–15] These strategies are often viewed as organizational support, which may mitigate the occurrence of work–family conflict (WFC) and minimize job and life dissatisfaction.[11,14,16]

Some of those organizational policies, however, may not be transferable to the profession of athletic training, particularly at the Division I level. Previous research within the athletic training profession suggests that WFC occurs because of a variety of organizational factors (eg, work time, inflexible work schedules, work overload)[1,2,17] and affects both married and single ATs. Because WFC occurs for ATs regardless of marital and family status, the term *work–life conflict* is more descriptive, but the terms are transposable. Such strategies as proper nutrition, time management, exercise, saying no, setting priorities, teamwork, support networks, and establishing sport-coverage policies have been suggested to help ATs meet the challenges of balancing work, family, and personal interests.[18–22] Additionally, the theory of integration,[22] by which an individual prioritizes both work and personal time, has become an increasingly popular technique to promote a balanced lifestyle.[18,22] For example, some major-league baseball teams have opted to provide players with benefits such as on-site child care and family lounges to help players create more time for family and personal obligations.[23,24]

Although recently published literature has provided insights into the causes of WFC and quality-of-life issues,[1–3,17] to our knowledge, no authors have yet investigated strategies or techniques used to promote balance among ATs. Ascertaining how ATs attempt to achieve a balanced life may provide valuable information regarding how to improve the quality of life enjoyed by ATs, which may in turn reduce the occurrence of job burnout, job dissatisfaction, and attrition within the athletic training profession. The purpose of our study, therefore, was 2-fold: (1) to confirm the sources that contribute to WFC and (2) to determine the practices, if any, currently used by ATs to promote a balanced lifestyle.

## METHODS

Qualitative methods are often employed by researchers seeking an in-depth understanding of human behavior and perspectives on particular experiences.[25,26] Our goal was to gain insight into strategies used by ATs to achieve a balanced life and the influence that workplace dynamics have on achieving that balance.

### Participants

A total of 28 ATs, 15 women and 13 men, participated in the study. At the time of data collection, 19 ATs were employed at the Division I Football Bowl Subdivision level and 9 at the Division I Football Championship level. The ATs had been certified by the Board of Certification for 12 $\pm$ 8 years, and their age was 35 $\pm$ 9 years. Of the 28 ATs, 7 were head ATs (HATs) and 21 were assistant ATs (AATs). The average work week for the participants was 64 $\pm$ 16 hours during the in-season and 45 $\pm$ 11 hours during the off-season. Table 1 provides demographic information for the ATs, who represented 16 National Collegiate Athletic Association universities and National Athletic Trainers' Association (NATA) Districts 1, 2, 3, 4, 9, and 10.

### Procedures

The study used online, asynchronous, in-depth interviewing through Husky CT (University of Connecticut, Storrs, CT), a Web-based management system. Online data collection is growing in popularity, particularly in-depth interviewing, as the method circumvents many of the difficulties presented by in-person interviewing, such as time, cost, and access to research participants.[25–32] Follow-up phone interviews were also used to validate findings of the study and to allow participants to clarify or expand upon their initial thoughts and responses to the questions. After gaining approval from the University's institutional review board, we purposefully selected participants for interviewing.[27,28] At the outset of the study, we identified inclusion criteria for participation (criterion sampling),[29] which included Board of Certification certification, employment within the Division I collegiate setting as a full-time staff member (HAT or AAT), and a minimum of 3 years of full-time experience. Initially, we contacted individuals with whom we were acquainted for study participation (convenience sampling)[26,33] and then asked those participants for access to additional participants (snowball sampling).[17,26,28,33] Recruitment of participants ceased once data saturation occurred and maximum-variation sampling was achieved.[28] Maximum-variation sampling ensured that we involved both sexes, both single and married participants, and those with and without children. We also involved ATs covering different sports and having different levels of responsibility (ie, HATs, AATs). This sampling procedure was chosen instead of a homogeneous sampling to gain a more global perspective of the work and life balance paradigm in collegiate athletics.[25,26,28] All participants were recruited via an e-mail, which included a description of the study, methods, and steps for participation. Consent was conceded by enrollment in the study.

**Table 1. Demographic Data**

| Variable | No. (%) |
|---|---|
| Men | 13 (46.4) |
| Women | 15 (53.6) |
| National Athletic Trainers' Association District | |
| I | 8 (28.6) |
| II | 6 (21.4) |
| III | 6 (21.4) |
| IV | 6 (21.4) |
| IX | 1 (3.6) |
| X | 1 (3.6) |
| Head athletic trainer | 7 (25) |
| Women | 2 (7.1) |
| Men | 5 (17.9) |
| Assistant athletic trainer | 21 (75) |
| Women | 13 (46.4) |
| Men | 8 (28.6) |
| Sport coverage | |
| Football | 11 (39.3) |
| Basketball | 8 (28.6) |
| Track | 4 (14.3) |
| Soccer | 3 (10.7) |
| Other | 2 (7.1) |
| Married | 17 (60.7) |
| Women | 9 (32.1) |
| Men | 8 (28.6) |
| Single | 11 (39.3) |
| Women | 6 (21.4) |
| Men | 5 (17.9) |
| With children | 13 (46.4) |
| Women | 5 (17.9) |
| Men | 8 (28.6) |
| Without children | 15 (53.6) |

After acknowledging interest in the study and completing the background (13-item) questionnaire to provide basic demographic information (eg, age, marital status, family status, years in the profession, number of hours worked in a week, travel schedule, and current sport assignment or position), each participant was e-mailed a log-in name and password for interview completion. Participants completed a series of 3 questions each week for 4 weeks (12 total questions). When they logged on, they had access to only the set of questions posted for that week, but they had the freedom to respond to the 3 questions at any time during the week; this allowed them to reflect upon the questions before answering. Questions were derived from the previous WFC literature[1–5,7] and were open ended (see Appendix 1 for the interview guide). To decrease the chance of misinterpretation or miscommunication of the material presented in the interview questions, a common concern with online interviewing,[30] we called on a panel of experts (n = 5) to review the interview guide for content and clarity. The panel included 2 athletic training educators, a qualitative researcher with 15 years of experience, and 2 ATs employed at the Division I level. Feedback from the panel was synthesized, and several minor changes were made to the text to increase the clarity of the questions before data collection.

Once data collection was initiated, participants received a weekly e-mail notification. Those who failed to respond to a posting were e-mailed a reminder. The rationale behind this time frame and data-collection method was to provide participants with demanding schedules the time and opportunity to express their opinions.[31] Once the participants completed the online portion, we contacted them by telephone to clarify findings, gain more in-depth information regarding their work environment, and substantiate the initial findings of the online portion of the study. Appendix 2 displays the follow-up interview questions. This step was added to ensure that those participants who were less fluent writers than speakers had the opportunity to accurately articulate their thoughts.[30] All follow-up interviews were transcribed verbatim, and all textual data were placed into a word-processing document for analysis.

## Data Analysis

The interview transcripts were analyzed using an inductive content analysis[34,35] by one researcher with previous experience in qualitative analysis. The analysis was performed by coding textual data with a conceptual label to capture its meaning. The coded concepts were then organized into lower-order themes (thematization).[28] As data analysis progressed, all themes and data were reevaluated and reorganized as necessary and, consistent with inductive content analysis[35,36] and other studies[37,38] using this method, the lower-order themes were grouped together to derive the higher-order themes. The process continued until 3 levels of themes emerged. Once data analysis was complete, the researcher shared the findings and transcripts with a second researcher who had previous inductive content analysis experience to validate the findings (the study's peer debriefer). The analysis process is consistent with basic, or generic, qualitative research studies by Wiersma and Sherman[35] and other qualitative researchers.[29,36]

Trustworthiness was established by member checking, peer review, and data triangulation.[26,28,35] After transcription of the follow-up interviews, the researchers shared the transcripts with all the participants as a form of member checking for clarity and accuracy. Additionally, the findings were shared with 5 participants so that we could be certain the emergent categories were viable and credible based on their personal experiences. The 5 participants were randomly selected and all agreed with the study's findings. Interview transcripts, coding sheets, and theme interpretations were shared with the peer debriefer, who had previous qualitative research experience. The peer, an athletic training educator with more than 15 years of research experience and a strong background in qualitative methods, ensured methodologic rigor. Data triangulation was established by interviewing ATs with years of athletic training experience who were employed in various positions (HAT, AAT) and at various levels within Division I (Football Bowl Subdivision level, Football Championship level) and by using both electronic- and telephone-interviewing techniques.

## Results

Three higher-order themes emerged from the data analysis: (1) antecedents to work–life conflict (Figure 1), (2) professional factors, and (3) personal factors. The themes of professional and personal factors characterize promotion of a balanced lifestyle. The overall dynamic, as perceived by this sample group of ATs, within Division I athletics regarding effective strategies to balance career and life demands is illustrated in Figure 2. Frequencies and percentages for the themes generated during data analysis are shown in Table 2. Each theme is presented below with supporting quotes. In all instances, pseudonyms are used to maintain confidentiality.

## Antecedents of Work-Life Conflict

The higher-order (third-order) theme, antecedents of work–life conflict, reveals aspects of the Division I athletic training role that lead to perceptions of conflict. The third-order theme was derived from 3 second-order themes: demands of the profession, control and flexibility of work schedules, and staffing patterns. All participants, regardless of age, years of experience, or marital and family status, experienced challenges during their careers regarding WFC, noting that their personal experiences may have differed in description, but their stories were comparable. The aforementioned themes capture their reflections regarding their experiences.

**Demands of the Profession.** Consistently, the nature of the profession was discussed as the catalyst to conflicts arising between an AT's professional and personal lives. The nature of the profession was summarized as the demands placed upon the AT to accomplish job-related responsibilities. Two major factors were defined by the demands of the profession: (1) hours and travel and (2) coaches' expectations and influence. Laney honestly said, "I think it is hard to focus on personal life when so much of my time is spent with people that I deal with professionally, not socially." Dan recounts similar experiences:

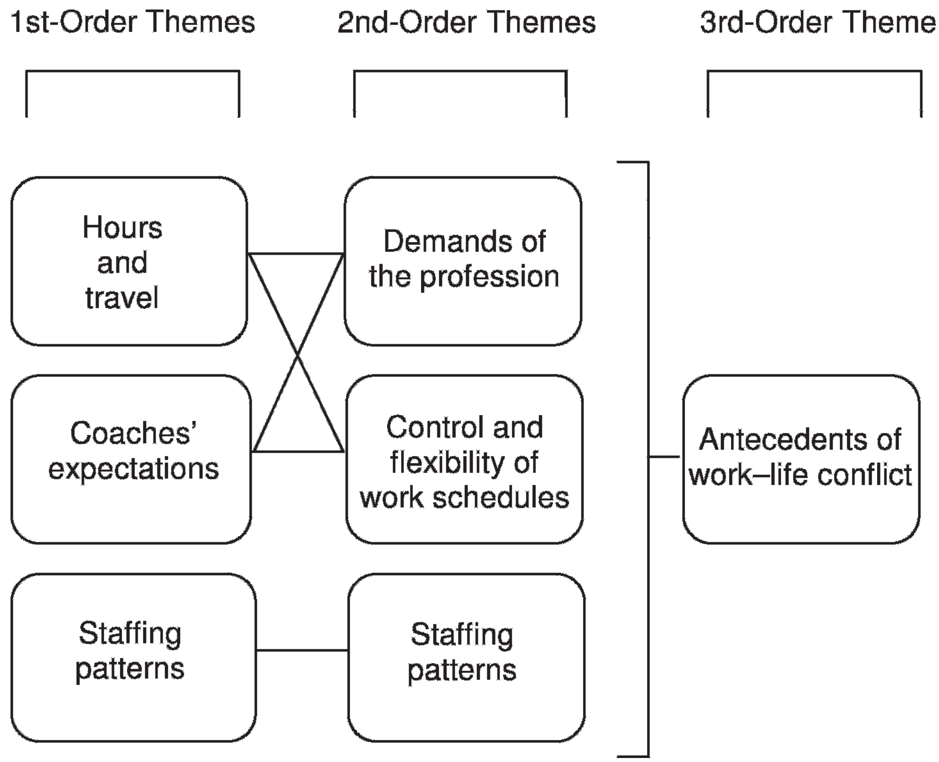


**Figure 1. Sources of work–life conflict.**

> I work so many hours that I don't have time to do the things that I like to do. I don't have the time to see my family and often miss holidays and family events. I would even go long periods of time without seeing friends that I didn't work with.

Brianna discussed how the long work hours affected her ability to connect with others outside the workplace:

> I have experienced challenges finding a balance between my personal and professional life. First it is important to realize the time constraints and travel requirements with being a Division I AT. I feel the most difficult thing for me personally to do is meet people outside of work in the area that I live.

Emma reflected on the chaos traveling causes to her work–life balance:

> Weekend after weekend of traveling can become very taxing. I never feel that I have any time for myself during the season. It becomes hard to keep up with simple daily things like grocery shopping, laundry, or corresponding with loved ones.

Kara summed it up by asking the question, "How do I have the same energy for my husband I have for my job after a 13-hour day?"

Several ATs mentioned the role of the coaching staff in allowing them to maintain a balanced lifestyle. Ultimately, the coach determines practice and game schedules. Many ATs felt that the coaches' expectations and the last-minute changes made to schedules created (or potentially created) conflicts. Milly, while commenting on what she could change about her current position, said, "I would like to see more coaches with their athletic trainers work as a team and work with their schedules. The coach needs to understand the sacrifice they're [the ATs] making at times." Scott talked about the evolution of daily practices and the expectations of the coaching staff for the AT to be present. "I know coaches who want coverage no matter the time. I have had coaches want practice at 6 AM and then again at 8 PM and expect medical coverage." Jen discussed the coach's ability to change practice schedules as the most problematic factor:

> Ultimately, if I could change something [that would help me manage more effectively], I would like to have more control over what the practice schedule is and not changing a planned practice time [it is the biggest thing that affects your day-to-day activities].

The role of the coach, specifically, including his or her control over practice schedules and expectations of their staff members, was discussed as an impediment to life balancing for ATs. As shown in Figure 1, the coach's expectations and control over work schedules can directly affect an AT's ability to manage professional and personal time.

**Control and Flexibility of Work Schedules.** Many ATs discussed the lack of control or the inflexibility of work schedules as the source of conflicts in managing their personal responsibilities. Scott stated, "Ultimately, I think if we had a little more control over scheduling instead of always having to be reactive, it would help in the job we do [and minimize the number of conflicts I personally have]." Harrietta discussed the sacrifices she has made personally to meet her job-related responsibilities and the effect of not determining her own schedule: "If coach schedules practice or there is a game—I'm there. I have no control over the

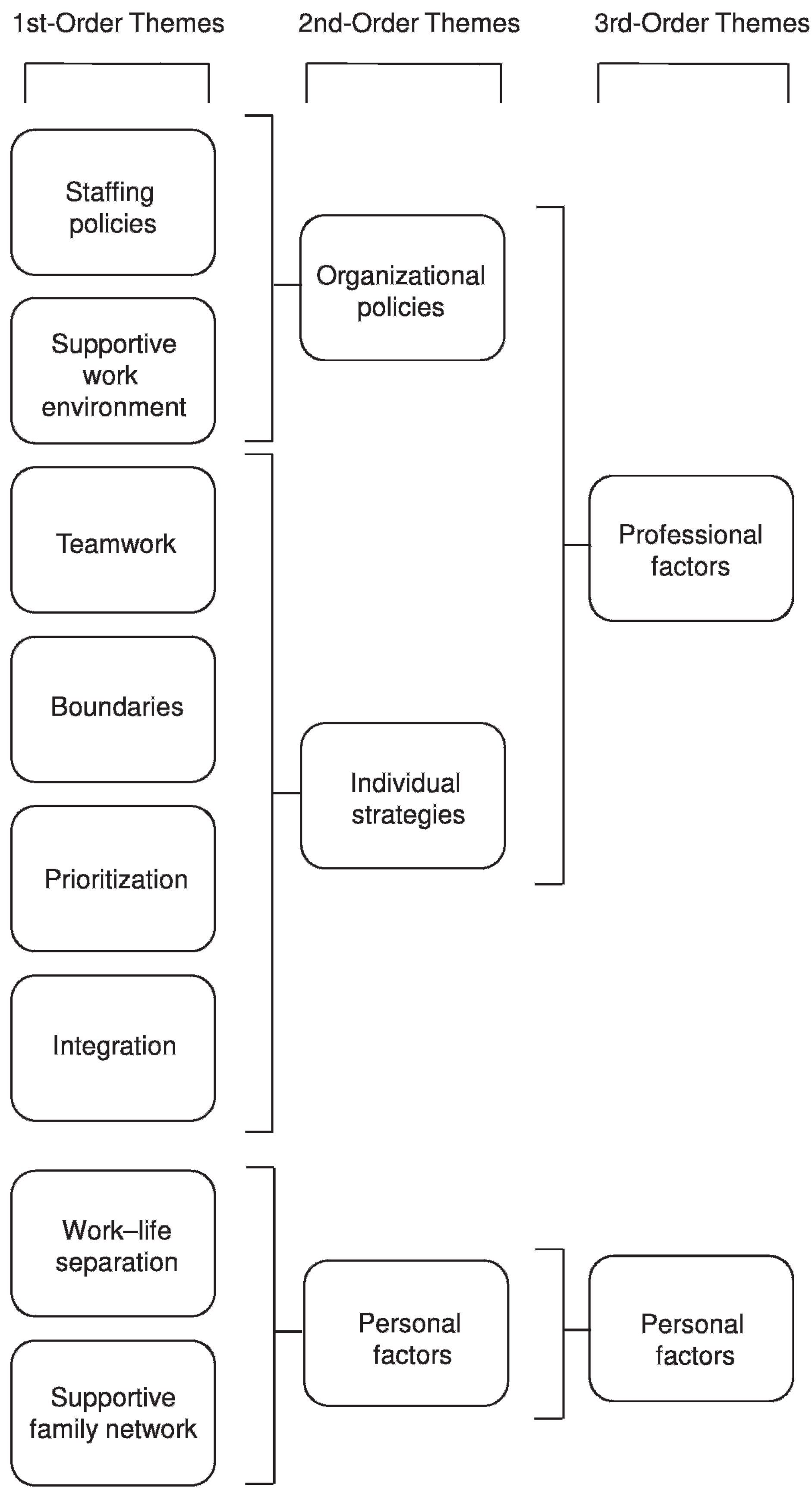


**Figure 2. Strategies to promote work–life balance in the Division I clinical setting.**

**Table 2. Frequencies of Responses by Themes for Achieving Balance**

| Theme | No. (%)[a] |
|---|---|
| Professional strategies | |
| Organizational policies | |
| Staffing patterns | 16 (57) |
| Supportive working environment | 18 (64) |
| Individual policies | |
| Teamwork | 19 (68) |
| Boundaries | 10 (36) |
| Prioritization | 14 (50) |
| Integration | 6 (21) |
| Personal strategies | |
| Separation | 10 (36) |
| Supportive family network | 25 (89) |

[a] The total number of responses for each theme was 28.

basic schedule of my day. I have sacrificed a lot of personal time due to my work schedule.'' Jen acknowledged the last-minute changes in work schedules as challenging in managing her family responsibilities, ''… adjusting schedules at the last minute. With 2 small children in day care, the last-minute change of practice time can cause problems and is most challenging.'' Adam faced similar challenges in spending time with his children because of scheduling changes: ''I try to make an effort to be flexible in my schedule when I can, but this is very difficult when you are on someone else's [coach's] schedule.''

**Staffing Patterns.** A lack of staffing was also mentioned by many of the ATs as a precipitating factor to work–life conflict. Tammy stated, ''I spent 2 years as an assistant AT … as 1 of 2 full-time ATs in charge of 15 sports. I frequently spent 85–90 hours per week working and traveling.'' As previously mentioned, Ken worried about his own as well as his staff's quality of life resulting from staffing patterns and budget cuts: ''… balancing everyone's schedules to maintain personal/professional balance will be difficult [if we lose staff].''

Thus, a combination of factors, as illustrated in Figure 1, contribute to WFC in the Division I clinical setting. Furthermore, experiences of WFC due to the aforementioned factors affect ATs regardless of their age and marital or family status.

## Professional Factors

The higher-order theme of professional factors is characterized as those strategies that can be applied to the workplace by either the organization or individuals. The professional-factors theme was derived from 2 second-order themes: (1) organizational policies and (2) individual strategies. Supportive working environment and staffing patterns were first-order themes, which typified the organizational-policies category. The second-order theme of individual strategies was derived from several first-order themes: (1) boundaries, (2) prioritization, (3) integration, and (4) teamwork.

**Organizational Policies.** Organizational policies reflect those tactics implemented by coworkers within the workplace to address work–life balance. Many such policies were a direct result of the employees themselves developing a workplace philosophy or belief, rather than the administration originating them. Participants spoke about the importance of a supportive working environment as key to successfully managing their personal and professional roles. Specifically, they commented on the need for teamwork among coworkers. This emergent theme, as indicated in Figure 1, plays a role in both the organizational theme and the individual policies discussed later in this section. Sharing and encouraging a teamwork attitude can help ATs achieve a balanced lifestyle. Many ATs bluntly stated that the key to their ability to find a balance was related to the teamwork atmosphere fostered by them, their coworkers, and the administration.

Kara stated: ''I am trying to create more balance by splitting coverage with the other football AT on staff [new position this year]. I am hoping that with 2 of us to cover the team, now things will be better.'' Sue offered,

> My coworkers are very helpful in trying to maintain a life balance. We try to help each other when we can by covering a part of practice so you can go home early, or traveling with a team so you can attend a family event.

Amy offered this advice for ATs in regard to attaining a balance:

> Surround yourself with coworkers with the same values [family oriented and team oriented]. [As a staff member] Always be willing to assist a coworker and go above and beyond, and the help will be there when you need it as well.

Jen described why, as a mother of 2 young children, she was able to maintain a balance and her sanity as a Division I AT:

> My coworkers are willing to help me out. This is why our system and staff here [at my institution] works. Our supervisors made a very strong effort to create an environment where we could feel comfortable stepping in for each other and helping out as needed. We created an environment where it is okay to have another AT once in awhile to help out.

Another working parent, Mary, discussed the role her administration and fellow colleagues played in her ability to manage a newborn with medical concerns while still meeting her professional responsibilities: ''I was able to balance this unique challenge because my administration and sports medicine colleagues supported me.'' A supportive philosophy was instrumental in creating balance for Division I ATs. A supportive work environment is necessary on many levels (eg, administration, staff), and many of the ATs discussed the need for all members of the staff to share the same vision. As Joe put it, ''my coworkers encourage personal time. We commonly offer to help cover games, etc. Our staff is close and understands the importance of life balance.'' Luke warned, ''having coworkers who don't share your vision [for life balancing] can be time consuming and hinder the vision for the program.''

Almost as important as having coworkers who support personal time is having an administration that shares the same philosophy. Gary, a HAT, discussed his beliefs:

> I have worked hard to establish an atmosphere that allows and encourages us to work together and to cover for each other when possible. I never want my staff to feel like they cannot do something because they don't have coverage or help.

Another HAT, Scott, described his goal of establishing a working model that encouraged and allowed his staff more of a balance: "I think we're getting closer to it here [a balance]. It's been one of the goals [we've/I've had]." Milly vocalized the importance of administrative support for successful life balancing:

> It starts with our boss. He certainly and definitively understands the need for space in our personal life and tried to accommodate our needs. He encourages us to take time off from work as needed for personal reasons and does not give us a hard time about it. He understands if we have desires to visit family or have doctor's appointments.

One caveat that did arise regarding a supportive, cohesive work environment fostered by both coworkers and administrators (HATs, athletic directors) was not taking advantage of those accommodations or of the flexible time made possible by coworkers. Amy summed it by stating, "I don't take advantage and use family as an excuse." Mike reiterated, "my coworkers have always let me have the option of going home and taking care of my personal obligations, but I also do not take advantage of this opportunity."

The number of staff members was another critical component to meeting personal obligations and finding a balance; that is, the sports medicine staff must be large enough to support a teamwork working environment. Jackson discussed the philosophy of his staff by saying, "we do a tremendous job (5 full-time and 5 GAs [graduate assistants]) of supporting each other when personal issues arise." Denise stated, "The administration has supported our department [mission for more personal time] with hiring of additional personnel." Another reflected on a previous position in which a lack of staff contributed to an imbalance within her life. Tammy said, "my biggest challenge before [at my former school] was an imbalance with staff-to-patient ratios. At my current institution, we have a rather large staff. One of the greatest benefits of our large staff is that people are willing to assist if someone requires help." Jake honestly felt that the foundation for a balanced lifestyle at the Division I level was linked to staffing: "providing enough support staff [to adequately cover and handle responsibilities]." Sue concurred, stating "I think more staff [would increase personal time]. Oftentimes you do not have one sport assignment, you get multiple ones. That is what makes the hours so long." One HAT felt he was able to help his staff the most in the last year because he had enough staff to adequately cover all practices and lifting sessions. Scott acknowledged, "that [allowing staff to have the time off] only comes when you have the amount of people you need. We have gotten very, very close to that here." Ken, another HAT, contemplated the negative effect the loss of staff members could have on work–life balance, "Should we lose position(s), balancing everyone's schedules to maintain personal/professional balance will be difficult while maintaining the same level of care."

**Individual Policies.** Individual policies were specific strategies addressed by many of the ATs regarding their attempts to establish a balanced lifestyle. Many of the discussions focused on the service-oriented nature of the profession as a precipitating factor for conflicts. To avoid conflicts and allow for more personal time, many ATs discussed setting boundaries. Bruce declared, "set boundaries and stick to them [this will help to achieve] that balance that we all strive to get." Kara, while articulating advice to new ATs, said, "set your boundaries early. Let your student-athletes and coaches know what are acceptable things to call you about during evenings and weekends [and what are not]." Kim talked about using work schedules as a way to establish boundaries and a routine, which in turn helped her create a balance. "Establishing rules and daily rehab/treatment time frames for athletes and coaches to follow has been an effective way for me to have a schedule where I know when I can expect down time." Others discussed using the word *no* as a method to establishing boundaries and a way to enjoy a more balanced lifestyle. Amy stated, "learn how to say *no*, but don't overuse the word. Only say *no* when your work–life balance, relationship, or family will be affected." Milly agreed:

> … concerning schedules and learning to value my time, I have learned to say *no* to things. If athletes need to be evaluated, I used [to] drop everything the minute they called. Now, I will have them wait for me.

Adam said, "don't be afraid to say *NO*." By establishing boundaries, such as setting treatment hours, saying *no*, or having specific call times, an AT can effectively do the job while still having a personal life.

Another common tactic used by the ATs was prioritization, or setting daily priorities. More often, it involved setting aside time for themselves during the day to accomplish personal tasks or obligations. Randy discussed using his lunch break as a way to fit in a workout: "… for myself, I exercise. I try to do it every weekday at lunch. This gives me time to rest and recover." Brianna echoed the value of using exercise as a stress-reduction and recovery technique: "Probably the most important thing I do [to maintain a balanced lifestyle] is I work out every day. It is the one thing I can do every day that is completely and utterly for me and no one else." Mike stressed making time for yourself, regardless of the activity, "… make sure to designate some time for yourself. Do something that you find as an outlet, and get away from work." Concurring with many of the ATs, Sue summarized finding a balance through prioritization: "I try to maintain a balance by prioritizing. I find that being able to put the things that are important to you first helps it from keeping you from getting absorbed by another aspect." Others mentioned the reality of not prioritizing the time for themselves because of work-related obligations. Kara frankly stated, "if there is a conflict, then the personal side [my time] is what gets thrown out the window."

The concept of integration was discussed only by those ATs with families and was seen as an effective tool to creating a balanced lifestyle and increasing family contact time. Scott said, "I try to include my daughters in as many work-related things as possible." Amy described the family-friendly environment at her institution: "There are kids all over our department, at intermittent times. No one takes advantage of it, everyone gets their jobs done, and everyone is exposed to less stress because they have the alternative to have their child with them at work if need be." Rachel attributed her ability to manage her children's schedules with her work schedules to integration:

> When my children were younger, I would bring them to work with me on Sundays. We only had a few hours of treatments at that time [and it was a way to spend time with them and meet my work obligations].

### Personal Factors

Personal factors were operationalized as strategies or circumstances used by the AT outside of the workplace. This higher-order theme consisted of 2 lower-order themes: (1) supportive family network and (2) work–life separation. Frequently, the ATs discussed and stressed the importance of their personal social networks, which included non-AT friends, spouses, peers, and family members (eg, parents, siblings, husband, children). Jackson stated, "My wife understands what I do and knows how my schedule (or lack of a consistent one) varies. The short version is my family accepts what I do for my career." Jen echoed this sentiment: "I am fortunate to have a very understanding husband." Harrietta acknowledged the encouragement she received from her family, which allowed her to manage her responsibilities more effectively:

> My family helps me maintain my life balance. They understand the importance of my job and the amount of time that… job takes. All in all, my family never makes me feel guilty about my life balance (or lack of balance).

Kara talked about her family's understanding with regard to scheduling of events and family gatherings:

> My family has learned to schedule around the football season, since I don't get a day off from August to December. This helps with the work–life balance so that I don't miss as many family gatherings.

A balanced lifestyle was very important to all participants, and many were able to achieve that balance more effectively through the support of their social networks.

Another frequent comment made by the ATs addressed separating their professional and personal lives. Jake bluntly stated, "Leave work at work." Taber's comments were consistent with this recommendation. He noted that the most important element in finding a balance was to "leave all of the issues and problems from work at work." Milly reflected upon her struggles with finding a balance and openly confessed not wanting her work to consume her. She found balance by

> not bringing work home [with me]. At the end of the day, if there is an individual injured, an exercise I need to make, or an evaluation I need to do better, I wait until the next day, when I am at work to do these things.

Making a clear distinction between work and personal life can help some ATs reduce the stress and challenges associated with this balance.

## DISCUSSION

The impetus for this study came from data transcription and analysis from a previous study examining WFC among Division I ATs.[1,7] The purpose of that study was to determine whether WFC was occurring within the profession of athletic training and what effect it had upon such constructs as job and life satisfaction, job burnout, and job retention.[1,7] Through the data-collection process, specifically through the one-on-one interviews, it became clear that many of the participants were experiencing a certain level of WFC. Several commented on methods to combat the conflicts they were experiencing because of the demands of their positions. Many encouraged future researchers to examine the practices being used to promote a family-friendly work environment within athletic training. Also highlighting this need for further investigation has been the increase in articles within the athletic training literature. Since 2005, *Athletic Therapy Today* has published 4 separate articles[2,18–20] and devoted an entire section to elements related to work and family balance and quality of life for ATs.[19–21] Several of the articles focused on suggested practices to help promote a balanced lifestyle for an AT and, although many of the recommendations are practical, they may not completely depict the situation (eg, clinical settings). Currently, a majority of the research examining successful policies focused primarily on the traditional employment sector, with little attention to nontraditional employment settings in which the work day is not 9 AM to 5 PM.

Beyond the suggestions of study participants to conduct this line of research, the need for investigation surrounding organizational policies and personal strategies for the promotion of work and family life balance lies in its documented consequences. In separate meta-analyses, Kossek and Ozeki[16] and Allen et al[38] found that in addition to life and job dissatisfaction, employees experiencing WFC were also experiencing job burnout, thoughts of leaving their positions or careers entirely, and a host of other non–work-related variables such as depression and marital dissatisfaction. Although neither study included ATs, the occurrence of WFC has been documented in the profession,[1–3,7] and its negative effect was much stronger for ATs than for other working professionals[7]; therefore, investigating strategies and policies to help promote a balanced life is crucial.

### Sources of WFC

We identified several antecedents of WFC, including demands of the profession, control and flexibility of work, and staffing patterns. These findings corroborate those of previous researchers[1,2] who characterized organizational factors such as work hours, travel, and work schedules as major catalysts to WFC that are reported to have a negative influence on quality of life in this population.[17]

Although WFC has been proposed to arise because of myriad factors,[13] for ATs in this study, the catalysts were grounded in the organizational structure of the workplace. This is not surprising, because athletic training is often characterized as a "time-intensive occupation,"[40,41] a description linked to higher reported levels of WFC.[1,7,42–44] Long work hours and travel are not unique to the athletic training profession; however, the lack of control over work schedules, coaches' demands and expectations, and inadequate staffing patterns are distinctive to the profession. Lack of control over work schedules and inadequate staffing patterns have been associated with WFC within the Division I clinical settings in the past.[1,2] These particular issues have not been associated with WFC in other professions, perhaps because of popular strategies such as flexible work schedules, flex time, and job sharing[5,12,14,45,46]; when these strategies are used appropriately, scheduling and staffing concerns no longer contribute to WFC.

Another factor that directly influenced control over work schedules was the role of the coaching staff. Understandably, last-minute changes regarding work schedules can affect an individual's ability to manage his or her personal life, and an AT is no exception. Again, organizational culture and work scheduling has been heavily associated with WFC,[12,13] and those employees who have control, or the perception of control, over their work schedules report less WFC than those who do not.[15]

### Balancing Work and Family: Professional Strategies

For participants in this study, 2 distinct avenues were available for achieving balance: organizational policies and individual workplace strategies. Many of the anecdotal suggestions within the athletic training literature were comparable with our findings.[18–20] On an individual level within the workplace, the need to establish boundaries with coaches and athletes was necessary for many of the ATs to maintain work–life balance. The reality is an AT employed at the interscholastic level will never enjoy a typical workday schedule; however, once the workday is complete, the focus should be on personal interests or domestic care obligations and not additional work responsibilities, which can often wait until the next day. Many strategies to establish boundaries in the workplace exist, but as documented in the aforementioned results and in editorials by Scriber and Alderman[19] and Mensch and Wham,[20] the use of the word *no* is a highly effective method. Being a team player, which is another key to successful fulfillment of work–life balance, does not always mean that an AT has to say *yes* to every additional responsibility or last-minute schedule change. Joe Robinson, a life-balancing expert, encourages the use of the word *no* to establish work and life boundaries and guarantees its success.[47]

Almost as important as establishing workplace boundaries is setting priorities. Setting priorities, defined by this group of ATs as setting aside time during the day for non–work-related activities such as exercising, going to lunch with a friend, or doing laundry, have been recommended by several experts in life balancing[47,48] and addressed by several keynote speakers at the NATA Annual Meeting and Clinical Symposia.[48,49] Instituting priorities can empower individuals, providing them with more control over their personal and professional responsibilities and schedules. Such control is key to fulfillment of work–life balance,[15] which is associated with a more productive, committed worker, reduced attrition in the workplace, and bolstered teamwork among staff members.[10,45]

Teamwork was especially important for this group of ATs in sustaining a balanced life. Regardless of marital or family status, ATs were able to have a sense of balance because of the teamwork culture. On many occasions, ATs were able to attend a child's recital, personal doctor's appointment, or wedding because a fellow AT was able to cover. A strong support system that includes coworkers has been mentioned previously as necessary to promoting life balance in athletic training, particularly for female ATs.[22] Furthermore, HATs and administrators should encourage teamwork among staff members because it provides a sense of organizational support, a critical link to improving work and life balance.[11,16,42,45]

The theory of integration, which has been suggested as a tactic promoting work–family balance,[18,50] was also reported by several of the married ATs as an effective way to address last-minute changes or child-care emergencies and even as a way to increase the amount of time spent with family. When appropriate, the ability to include family in the workplace environment can ease the stresses related to WFC. Integration may also be of value for other ATs, regardless of their marital or family status. As with prioritizing personal time regardless of the time of day, using integration to offset lulls or changes in schedules can help an AT achieve a balance. For example, an AT may choose to go for a run, do laundry, or have lunch with a friend during "working" hours when he or she does not have taping duties to complete, rehabilitation programs to oversee, or practice to cover. Although at work, the AT is choosing to use this period of time for personal activities and, as noted earlier, setting priorities can help an individual to find a sense of balance. A direct correlation existed between an increase in "me" time and achievement of balance.[19] Similarly, in a recent study[44] of professional role commitment, ATs identified time for rejuvenation as a critical aspect of maintaining their commitment over an extended period of time. A period of rejuvenation not only was time away from the day-to-day role of the AT but also provided time to address personal needs.

### Personal Strategies

Finding a balance between their personal and professional lives is unquestionably essential for the ATs in this study, and the basis for achievement is a personal support network (Table 2). Relying on family, friends, and coworkers has been cited as a key component in fulfilling work and life balance.[22,50] Similarly, in an editorial addressing the personal and professional satisfaction of ATs, family support was highlighted as instrumental in attaining a balanced lifestyle.[21] On an individual basis, support was defined in a variety of ways, but it was typically described as the understanding and flexibility of friends and family regarding the nature of the AT's professional demands and responsibilities. Many of the statements made by the participants in this study echoed those of Kaiser,[21] who emphasized the need for time away from the workplace and the need for ATs to surround themselves with those who can empathize with the unique job responsibilities of an AT. Our findings relate to previous research[44] in ATs that underscored the role of networks to obtain social support and succeed in one's work role.

We are not suggesting that an AT's spouse's career is less important than the AT's career, but it seemed necessary for many of the married ATs to have a spouse with a more flexible work schedule to accommodate the working demands of the AT. Future researchers may investigate the influence of a spouse's career on work–life balance as well as the overall life satisfaction of the AT. Just as a supportive organizational culture affords an employee the ability to attend to family and personal responsibilities, a supportive family network allows the AT to adapt and handle the long work hours and lack of control over work schedules. As scholars continue to investigate effective policies for fulfillment of work–life balance, the influence of supportive family networks outside the workplace should also be studied because of the current paucity of literature on the topic.

The theory of separation, although becoming less popular in the literature,[50] appears to provide ATs with an effective strategy in reducing the influence of work on their personal lives. At the core, the theory of separation views work and life as distinct, independent spheres between which individuals attempt to create a distinct division.[50] Separation, an unfavorable term for many work–life scholars,[43,48,50] suggests that work is not part of life; however, for this group of working professionals, it appeared to provide the necessary relief from the pressures and stresses placed upon them in the workplace. Furthermore, the mindset of separation may allow ATs to increase both career and personal-life satisfaction by not allowing them to negatively influence one another. Several of the ATs attributed their sense of balance to time spent with family or on leisure activities and focusing all their energy while at home with their families, rather than on work issues or responsibilities, a strategy also discussed by Kaiser.[21] The theory of separation for this group of ATs may be defined more loosely: that working individuals should concentrate their energies on a specific aspect of their lives (eg, working or spending time with family) instead of trying to multitask or allowing responsibilities to spill over from one realm into the other. Furthermore, the emphasis should be on the quality of work or task completion, rather than on the time spent performing the specific activity. Ultimately, a balanced lifestyle is in the eye of the beholder (balance is defined differently by each person), and the hope is that once a balance is achieved, contentment or personal satisfaction follows.

## Limitations

The strategies and policies resulting from this study may not be transferable to all clinical settings because they come from a small (although random) sample. Additionally, the suggestions and thoughts of the participants in this current study may not reflect those of all ATs practicing clinically, but these personal experiences form a foundation for understanding successful practices used to reduce the occurrence of WFC and to achieve work–life balance. This was an exploratory study used to investigate a more global picture within the Division I setting; therefore, future inquiries should be more focused on specific samples (with respect to sex or marital status, for example) within this setting.

## Implications

Intuitively, every working professional at some juncture in his or her life struggles with finding a balance, but given the unique job responsibilities of an AT, the struggles are likely to be exacerbated or prolonged. Fortunately, this group of ATs demonstrated that with hard work, communication, and support, attaining a balance is possible within the Division I clinical settings. Although WFC is prevalent in athletic training, as evident by our reported results and previous AT literature,[1–3,17] and will continue to occur, several organizational policies and personal strategies can be implemented to help reduce conflicts that may arise. When integrated, the strategies can help the AT to achieve a balance between professional and personal lives. We encourage ATs to strongly consider the strategies presented in this manuscript and recommend selecting life-balancing techniques that meet the individual AT's professional and personal goals and needs. Furthermore, the results generated can assist the AT individually, the sports medicine department collectively, and the NATA globally. At any stage of their careers, ATs can learn to set boundaries and understand at times it is acceptable to "just say no," especially if their personal satisfaction or family time may be affected. Also, ATs should remember to take time for themselves by being involved with outside interests; doing so will help to promote a sense of balance and encourage a more positive outlook on life. Teamwork among coworkers should be supported at all levels, including by the individual, HATs, and administrators. This strategy by far, along with having a strong support network, was most important in giving ATs the ability to manage their career demands and personal responsibilities. Athletic administrators and HATs should also explore possibilities to allow ATs to have more control over their schedules. Flexible working schedules and control over one's work schedule are effective strategies to help employees meet their responsibilities both at work and at home.[4,5] Flexible work schedules in the athletic training environment may be more structured (eg, choosing a particular time of day to accomplish tasks, rather than working from home) than in other working environments but can still allow the AT to accomplish nonwork tasks on certain days.

In its strategic plan,[51] the NATA indicated the need for an increase in members' personal and professional satisfaction. To move one step closer, the NATA needs to investigate ways to enforce the recommendations of the Task Force to Establish Appropriate Medical Coverage for Intercollegiate Athletics[52] regarding appropriate medical coverage for intercollegiate athletics. Falling short of the recommendations, as many departments do, is often the impetus for WFC within this population. Moreover, the NATA should encourage and support teamwork and job sharing (interchangeability of staffing) within sports medicine departments. Inevitably, these accommodations will be the most important elements in helping ATs to achieve a balanced lifestyle, particular in the current economic climate. Job sharing or interchangeability of staff members simply means that each member of the sports medicine staff is qualified to provide medical care for an athlete, regardless of his or her specific sport assignment, and can do so when necessary. Future research, particularly focusing on the influence of staffing shortages, family-friendly working environments, and organizational support on WFC within athletic training, is necessary. Furthermore, although we studied a stratified sample of participants, future authors should study a more homogeneous sample to characterize demographic categories such as single ATs, women versus men ATs, married ATs, and married ATs with children.

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**Appendix 1. Semistructured Interview Guide**

1. Could you give me a little bit of background about your professional career and what made you pursue a position in the collegiate setting?
2. Describe an ideal working environment in athletic training? Is it obtainable in your current work environment or another work setting?
3. What do you feel is, or has been, your greatest challenge as an athletic trainer?
4. Reflect on the challenges that you have faced and describe what you have done to effectively deal with those challenges.
5. How important is a balanced lifestyle to you? Please describe to me, if it is, how you are able to maintain a balance between your professional and personal life?
6. Have you experienced challenges finding a balance between your personal and professional life? If so, share an instance when you have faced this challenge.
7. What factors have contributed to the challenge? If not, why haven't you had challenges?
8. In what way have coworkers helped or hindered your ability to maintain life balance?
9. In what way has your administration helped or hindered these challenges?
10. How does your family (support system) help or hinder in these challenges?
11. Discuss if working in the athletic training profession provides a suitable working environment to achieve a balance.
12. If a new athletic trainer was just about to enter this work setting, what advice would you give him/her to help them maintain a balanced life?

**Appendix 2. Follow-Up Interview Questions**

1. If you could change anything about the intercollegiate setting that you work in, what would it be? Why?
2. Have your expectations/understanding of the job changed since your early years in the profession?
3. Reflect upon your thoughts of maintaining a balance when you first entered the profession. How does it compare to now? Has it changed? If so, how?
4. If you are having a hard time finding a balance in your life, why do you continue to work in that setting?

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# National Athletic Trainers' Association Position Statement: Prevention of Pediatric Overuse Injuries

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***Objective:*** To provide certified athletic trainers, physicians, and other health care professionals with recommendations on best practices for the prevention of overuse sports injuries in pediatric athletes (aged 6–18 years).

***Background:*** Participation in sports by the pediatric population has grown tremendously over the years. Although the health benefits of participation in competitive and recreational athletic events are numerous, one adverse consequence is sport-related injury. Overuse or repetitive trauma injuries represent approximately 50% of all pediatric sport-related injuries. It is speculated that more than half of these injuries may be preventable with simple approaches.

***Recommendations:*** Recommendations are provided based on current evidence regarding pediatric injury surveillance, identification of risk factors for injury, preparticipation physical examinations, proper supervision and education (coaching and medical), sport alterations, training and conditioning programs, and delayed specialization.

***Key Words:*** adolescents, children, chronic injuries, microtrauma, growth, development

Overuse injuries in the pediatric population represent a significant health care concern. Some reports and clinical observations[1,2] indicate that 50% of pediatric patients present to sports medicine clinics for chronic injuries. In addition to their costs (direct and indirect medical expenditures), these injuries also result in lost participation time, numerous physician visits, and lengthy and often recurring rehabilitation.[3–5] Furthermore, athletes who sustain recurrent overuse injuries may stop participating in sports and recreational activities, thus potentially adding to the already increasing number of sedentary individuals and the obesity epidemic.

In the pediatric population, overuse injuries can include growth-related disorders and those resulting from repeated microtrauma.[6] Growth-related disorders include Osgood-Schlatter disease, Sever disease, and other apophyseal injuries. Overuse injuries resulting from repetitive microtrauma and chronic submaximal loading of tissues include stress fractures, similar to those described in adult athletes.[6] However, overlap exists between broad classifications; some growth-related disorders may occur in sedentary children but much less often than in their active peers.[6] Regardless of the cause, these injuries can result in significant pain and disability. Although little research has identified causative factors for overuse injuries in children and adolescents, these injuries may be caused by training errors, improper technique, excessive sports training, inadequate rest, muscle weakness and imbalances, and early specialization.[6–10] More than half of all reported overuse injuries are speculated to be preventable,[5] but few empirical data support this statistic.

The purpose of this position statement is to provide certified athletic trainers, physicians, and other health care professionals with current best practice recommendations regarding the prevention of overuse injuries in pediatric athletes, including children (aged 6–12 years) and adolescents (aged 13–18 years).[11] Even though specific age ranges have been identified, it is important to note that the occurrence of puberty, followed by skeletal maturity, is a far more important marker of maturity than chronologic age when managing pediatric overuse injuries. In particular, this position statement will provide recommendations based on current evidence (Table 1) pertaining to injury surveillance (eg, incidence, prevalence), identification of risk factors for injury, preparticipation physical examinations (PPEs), proper supervision and education (coaching and medical), sport alterations, training and conditioning programs, and delayed specialization.

## RECOMMENDATIONS

### Injury Surveillance

1. Research should be devoted to improved understanding of the prevalence, incidence, and economic cost of overuse injuries among pediatric athletes in the United States and should focus on prevention and treatment of these overuse injuries.[12,13] *Evidence Category: C*

**Table 1. Strength of Recommendation Taxonomy (SORT)[a]**

| Strength of Recommendation | Definition |
|---|---|
| A | Recommendation based on consistent and good-quality patient-oriented evidence[b] |
| B | Recommendation based on inconsistent or limited-quality experimental evidence[b] |
| C | Recommendation based on consensus, usual practice, opinion, disease-oriented evidence,[b] or case series for studies of diagnosis, treatment, prevention, or screening |

[a] Reprinted with permission from "Strength of Recommendation Taxonomy (SORT): A Patient-Centered Approach to Grading Evidence in the Medical Literature," February 1 2004, American Family Physician. ©2004 American Academy of Family Physicians. All Rights Reserved.

[b] Patient-oriented evidence measures outcomes that matter to patients: morbidity, mortality, symptom improvement, cost reduction, quality of life. Disease-oriented evidence measures intermediate, physiologic, or surrogate end points that may or may not reflect improvements in patient outcomes (ie, blood pressure, blood chemistry, physiological function, and pathological findings).

2. Funding and support for research into the prevalence, incidence, prevention, and treatment of pediatric overuse injuries should be increased.[12,13] *Evidence Category: C*
3. All athletic health care providers should participate in injury-surveillance efforts, including accurate documentation in keeping with good clinical practice, and Web-based and other registries.[12–14] *Evidence Category: C*
4. Resources and training for athletic health care providers (eg, certified athletic trainer, physician, physical therapist) to collect high-quality injury data must be developed.[12,13] *Evidence Category: C*

### Preparticipation Physical Examination

1. The PPE should be used as a means to screen each athlete for potential risk factors, including injury history, stature, maturity, joint stability, strength, and flexibility, which may be important for preventing recurrent injuries.[5,6,15,16] *Evidence Category: C*
2. Children and adolescents with noted deficits on the PPE should be referred to appropriate medical specialists and health care providers (eg, physician specialist, certified athletic trainer, physical therapist) for further evaluation and corrective rehabilitation.[5,15] *Evidence Category: C*
3. Robust documentation and injury-surveillance systems need to be developed to link PPE findings with injury, thereby identifying which measured factors may confer increased risk.[14,17] *Evidence Category: C*
4. More research is needed to improve the effectiveness of the PPE, including strategies to implement the beneficial components more consistently and efficiently in the context of broader health-supervision and morbidity-prevention efforts for adolescents.[14,17] *Evidence Category: C*

### Identification of Risk Factors

1. Arm pain, fatigue, and decreased throwing performance should be recognized by athletes, coaches, parents, and medical personnel as early warning signs of potential overuse injuries in pediatric throwers.[18,19] *Evidence Category: A*
2. Decreasing the volume of pitches as a means to prevent overuse injuries in throwing athletes is recommended.[19–21] *Evidence Category: A*
3. Health care professionals should recognize that certain anatomic factors may predispose the athlete to overuse injury, including leg-length discrepancies, genu valgus, genu varus, pelvic rotation, and generalized joint hypermobility.[9,10,22–24] *Evidence Category: C*

### Coach Education and Medical Supervision

1. Pediatric athletes, parents, and coaches should be educated about the signs and symptoms of overuse injuries, and athletes should be instructed to notify an adult when such symptoms occur.[18,19,25] *Evidence Category: A*
2. Coaches of youth and high school sports should have certifications or credentials identifying specific knowledge in areas related to sports safety, sports techniques and skills, psychosocial aspects of childhood and adolescence, growth and development, and common health and medical concerns.[13,16,26,27] *Evidence Category: C*
3. Organized youth and interscholastic sports should be supervised by adults, ideally those with knowledge and training in monitoring for overuse injuries.[5,13] *Evidence Category: C*
4. Medical personnel with training and education in pediatric sports injuries should be identified as referral sources to recognize, evaluate, and rehabilitate suspected overuse injuries.[14,16]*Evidence Category: C*

### Sport Alterations

1. Emerging evidence indicates that the sheer volume of sport activity, whether measured as number of throwing repetitions[18–21,28] or quantity of time participating,[29,30] is the most consistent predictor of overuse injury. Efforts should be made to limit the total amount of repetitive sport activity engaged in by pediatric athletes to prevent or reduce overuse injuries. *Evidence Category: B*
2. Although injury thresholds are yet to be determined for specific activities and age ranges, some data suggest a general guideline of no more than 16 to

20 hours per week of vigorous physical activity by pediatric athletes.[30] *Evidence Category: B*

3. Alterations or modifications to the existing rules for adult sports may help to prevent overuse injuries in pediatric athletes and should be considered by coaches and administrators for sports in which youth rules are lacking.[5,13,31] *Evidence Category: C*
4. Adults should ensure that pediatric athletes play only 1 overhead throwing sport at a time, avoid playing that sport year-round, and use caution when combining pitching with other demanding throwing positions (eg, pitch 1 day and catch the next day) to ensure adequate time for recovery.[7,28,32] *Evidence Category: C*
5. Parents and coaches should restrict the use of breaking pitches in order to prevent pitching-related arm injuries.[20] If an individual pitcher can throw breaking pitches on a limited basis and remain symptom free, then it may be allowed; however, if the use of this pitch precedes the development of any throwing-related symptoms, it should be immediately terminated and the athlete should seek medical attention. *Evidence Category: C*
6. Pitching limits should be established for players 9 to 14 years old: full-effort throwing (ie, in competition) should be limited to 75 pitches per game, 600 pitches per season, and 2000 to 3000 pitches per year.[20,33] *Evidence Category: B*
7. Pitchers between 15 and 18 years of age should throw no more than 90 pitches per game and pitch no more than 2 games per week.[21,33]*Evidence Category: C*

### Training and Conditioning Programs

1. Preseason and in-season preventive training programs focusing on neuromuscular control, balance, coordination, flexibility, and strengthening of the lower extremities are advocated for reducing overuse injury risk, especially among pediatric athletes with a previous history of injury.[34–36] *Evidence Category: A*
2. All pediatric athletes should begin participating in a general fitness program, emphasizing endurance, flexibility, and strengthening, at least 2 months before the sport season starts.[5,9,37,38] *Evidence Category: C*
3. Pediatric athletes should have at least 1 to 2 days off per week from competitive practices, competitions, and sport-specific training.[12,31] Coaches and administrators should consider these required days off when organizing season schedules. *Evidence Category: C*
4. Pediatric athletes should participate on only 1 team of the same sport per season when participation on 2 or more teams of the same sport (eg, high school and club) would involve practices or games (or both) more than 5 days per week.[31] *Evidence Category: C*
5. Progression of training intensity, load, time, and distance should only increase by 10% each week to allow for adequate adaptation and to avoid overload.[5,31] *Evidence Category: C*
6. After injury or delayed time without throwing, pediatric throwing athletes should pursue a gradual return-to-throwing program over several weeks before beginning or resuming full throwing activities.[7,32] *Evidence Category: C*

### Delayed Specialization

1. Pediatric athletes should be encouraged to participate in multiple sports and recreational activities throughout the year to enhance general fitness and aid in motor development.[5,13] *Evidence Category: C*
2. Pediatric athletes should take time off between sport seasons and 2 to 3 nonconsecutive months away from a specific sport if they participate in that sport year-round.[31] *Evidence Category: C*
3. Pediatric athletes who participate in simultaneous (eg, involvement in high school and club sports at the same time) or consecutive seasons of the same sport should follow the recommended guidelines with respect to the cumulative amount of time or pitches over the year.[31] *Evidence Category: C*

## BACKGROUND AND LITERATURE REVIEW

Repetitive stress on the musculoskeletal system without adequate and appropriate preparation and rest can result in chronic or overuse injuries in athletes of any age. In children and adolescents, this fact is complicated by the growth process, which can result in a unique set of injuries among pediatric athletes. Growth-related injuries most frequently affect the epiphyseal plates, where long bone growth occurs, and the apophyses, which serve as the bony attachments for musculotendinous units.[6] Compression is usually responsible for epiphyseal injuries, whereas repeated tension or traction forces injure the apophyses.[39] Differences in growth rates between the epiphyses and apophyses and between bone and muscle tissue are factors in apophyseal injury risk. These different growth rates may lead to relative myotendinous inflexibility and increased traction forces on the apophyses, contributing to traction apophyseal injuries.[40,41] In throwers, repetitive microtrauma can lead to further bony insult, resulting in capitellar osteochondritis dissecans, a localized lesion of uncertain cause that involves the separation of articular cartilage and subchondral bone.[42,43] Although most cases of osteochondritis dissecans resolve without consequence, lesions that do not heal after surgical intervention or a period of reduced repetitive impact loading may be responsible for future sequelae, including degenerative changes.[44]

Growth-center injuries may have long-term physical consequences and affect normal growth and development.[16,40] However, little high-quality evidence supports or refutes this suggestion. In a systematic review[45] of repetitive loading in gymnasts, females were at risk for stress-related injuries of the distal radius, including distal radial physeal arrest, but the lower-quality evidence of most of the included studies limited the strength of conclusions regarding whether physeal injury can inhibit radial growth. In a more recent systematic review,[16] 12 studies of baseball pitchers (3 case series, 9 case studies) with acute or chronic physeal injuries related to organized sport were analyzed. Stress-related changes were reported in all studies, including physeal widening in 8 reports, osteochondritis and radiographic widening of the proximal humeral growth plate in 2 reports, and humeral physis in 1 report.[16] Most of these patients improved with rest and were able to return to baseball, although some did not continue to pitch.

Data from lower extremity physeal injury studies were also extracted for review. Ten studies[16] of lower extremity physeal injury revealed that these injuries occurred mainly in runners, but soccer, tennis, baseball (catcher), and gymnastics athletes also showed radiographic changes of physeal widening. Among the 17 studies (11 case reports, 6 case series) of physeal injury in gymnasts, traumatic physeal arrest was described in 1, stress changes or fractures in 6, physeal widening in 5, and premature growth-plate closure in 5. In the 8 cross-sectional gymnastics studies reviewed, a distal physeal stress reaction was noted on radiographs from 10% to 85% of the athletes. Although the authors concluded that stress-related physeal injuries in pediatric athletes often resolve without growth complication after adequate rest and rehabilitation,[16] prospective, randomized studies must be performed to provide stronger evidence before clinicians should relax their vigilance concerning the potential for growth disturbance.

An estimated 50% of overuse injuries in physically active children and adolescents may be preventable.[5] The prevention of pediatric overuse injuries requires a comprehensive, multidimensional approach that includes (1) improved injury surveillance (ie, improved understanding of epidemiology), (2) identification of risk factors for injury, (3) thorough PPEs, (4) proper supervision and education (both coaching and medical), (5) sport alterations, (6) improved training and conditioning programs, and (7) delayed specialization. This preventive approach has been advocated by several prominent sports and health care organizations, including the American College of Sports Medicine,[5] the World Health Organization and International Federation of Sports Medicine,[13] the American Academy of Pediatrics,[31] and the International Olympic Committee.[12]

## Injury Surveillance

Before implementing any new prevention strategies or aiming to improve injury management, we must have adequate studies of epidemiology and a good understanding of the risk factors for pediatric overuse injuries.[15] The literature regarding the epidemiology of overuse injuries in pediatric athletes is scarce at best, particularly the literature concerning American children.

However, the epidemiology of chronic injuries has been investigated in several international studies. In a 2003 Japanese study,[46] the authors reviewed 196 stress fractures (125 males, 71 females) among 10 726 patients over a 10-year period. The average age of those with stress fractures was 20.1 years (range, 10–46 years), with 42.6% of patients between the ages of 15 and 19 years. The location of the stress fracture was somewhat specific to sport: the olecranon in baseball players, ribs in rowers, and tibial shaft stress fractures in ballet dancers, runners, and tennis, basketball, and volleyball players. Basketball players also sustained stress fractures to the metatarsals, whereas track athletes and soccer players incurred stress fractures to the tibial shaft and pubic bone. The authors concluded that stress fractures were common in high-functioning adolescent athletes, with similar proportions among male and female athletes. In another Japanese study[29] of stress fractures in 208 athletes under the age of 20 years, the researchers found that the peak age of occurrence was 16 years, the most frequent site was the tibial shaft, and basketball was the sport most commonly associated with stress fractures. A 2006 retrospective study[47] of stress fractures among 25 juveniles demonstrated that the age of onset was 12.9 ± 4.3 years (range, 3–17 years) and the tibia was most often affected (48%, n = 13), followed by the metatarsals (18.5%, n = 5). Using data from the High School Report Injuries Online (RIO) injury surveillance system, Fernandez et al[48] reported that 4350 athletic injuries occurred among athletes participating in 9 high school sports during 1 academic year. Although these authors did not focus solely on overuse injuries, they noted that 53% (n = 2298) of these injuries were to the lower extremity; 2% of these injuries were classified as tendinitis and 1.3% as stress fractures. Specific investigations of the epidemiology of overuse injuries are warranted in the high school population.

Although studies on the general prevalence of pediatric overuse injuries are lacking, investigators have addressed the sport-specific prevalence of overuse injuries. Dubravcic-Simunjak et al[2] retrospectively surveyed 469 elite junior figure skaters in Croatia, with 42% of female skaters and 45% of male skaters self-reporting an overuse injury at some point in their skating careers. In female singles ice skaters, the most frequent injury was a stress fracture (approximately 20%), followed by patellar tendinitis (14.9%). Male singles ice skaters were more likely to experience jumper's knee (16%), followed by Osgood-Schlatter disease (14.2%). Maffulli et al[49] reported on overuse injuries of the elbow among elite gymnasts in the United Kingdom and found that 12 elbows of 8 patients (aged 11–15 years) displayed a spectrum of radiologic abnormalities, including olecranon physis widening and epiphyseal fragmentation.

In a recent investigation of Norwegian soccer players, the rates of overuse injuries were 0.2 (95% confidence interval [CI] = 0.1, 0.4) and 0.4 (95% CI = 0.0, 0.8) per 1000 player-hours in 6- to 12-year-old boys and girls, respectively.[50] An increase in the incidence of overuse injuries was noted in an older cohort (13–16 years old) of boys (0.7, 95% CI = 0.4, 1.0) and girls (0.7, 95% CI = 0.3, 1.1) per 1000 player-hours, with the relative risk (RR) of overuse injury calculated as 2.9 (95% CI = 1.3, 6.4) and 1.7 (95% CI = 0.6, 5.5) in older boys and girls, respectively.[50] In addition, 87% of the reported overuse injuries resulted in time loss from soccer that ranged from 1 to more than 21 days. Similarly, LeGall et al[51] investigated the incidence of soccer-related injuries in elite French youth players and found that those younger than age 14 had more injuries during training sessions (ie, practices) and more growth-related overuse injuries, whereas older athletes more often sustained injuries during games. Overuse injuries accounted for 17.2% of all injuries and were mainly classified as tendinopathies (n = 108, 9.4%), osteochondroses (n = 72, 6.3%), or other overuse (n = 19, 1.6%). In a follow-up study of adolescent female soccer athletes over 8 seasons, overuse injuries accounted for 13.4% of all injuries.[52]

We need to better understand the prevalence, incidence, and economic impact of overuse injuries among pediatric athletes in the United States. Although few data are currently available about overuse injuries, the more than 7.5 million young people who participate in interscholastic sports[53] and millions of others who participate in youth sports programs across the country represent a very large at-risk population worthy of the expenditure of time, effort, money, and improved surveillance by clinicians and researchers alike.

## Preparticipation Physical Examination

A consensus has emerged that the PPE, as defined by several leading medical and allied health specialty societies, is the primary means of identifying at-risk athletes and initiating preventive measures.[5,6,14,15,17] The main objectives of the PPE are to detect life-threatening or disabling medical or musculoskeletal conditions and to screen athletes for medical or musculoskeletal conditions that may predispose them to injury or illness.[17] In the context of this position statement, the history and musculoskeletal examination are important in detecting and possibly preventing overuse injuries. Additional information on other aspects of the PPE can be obtained from the *Preparticipation Physical Evaluation* monograph.[17]

The history portion of the PPE should be used to recognize previous injuries and other possible signs of overtraining. Many overuse injuries can be identified from the answers provided in the history component.[17] Furthermore, a history of stress fractures or chronic or recurring musculoskeletal injuries may be associated with nutritional insufficiencies, which should be investigated as needed.[17]

The physical examination of the musculoskeletal system should include evaluation of the athlete's physical stature and maturity (Tanner stage) and any deficits in strength and flexibility.[5,17] In addition, the stability, symmetry, and range of motion of all joints and the relative symmetry, strength, and flexibility of all major muscle groups should be evaluated. These musculoskeletal assessments include range-of-motion tests, manual muscle tests, joint stress tests, flexibility tests, and balance tests, compared bilaterally. The *Preparticipation Physical Evaluation*[17] describes the general 14-point musculoskeletal screening examination as an acceptable approach to evaluate the musculoskeletal system in athletes who are asymptomatic and without a history of previous injury. If the athlete describes a previous injury in the history portion or pain or positive findings are noted on the general screening examination, a more thorough joint-specific examination should be conducted.[17] Ideally, a biomechanical assessment or functional screening test(s) should be incorporated to evaluate overall posture, gait mechanics, core stability, and functional strength.[54] This may include either a single functional screening test, such as the overhead squat test,[55] or a series of tasks[56] to identify abnormal movement patterns. However, these tasks have yet to be validated in the pediatric population. Any deficits or concerns should be discussed with the athlete and parent, along with recommendations for correcting these deficits, including referral to a physician specialist, athletic trainer, or physical therapist if needed.[5,14,15] Future researchers should focus on improving aspects of the musculoskeletal history, validating the general 14-point musculoskeletal screening examination and incorporating additional screening tests as possible predictors of overuse injuries.

A well-designed PPE can serve as a screening process from which prevention mechanisms can be developed.[57] This process should be simple to administer and reliable and should use a combination of anthropometric and biomechanical measures to identify risk factors. Unfortunately, the PPE is often incompletely and inconsistently delivered. In most states, the PPE is mandated for high school athletes, but it is often not a requirement for those participating in club-based or youth sports. Required elements in the history and physical examination vary widely and are often not consistent with published national guidelines.[58] The *Preparticipation Physical Evaluation*[17] suggests that the ideal location for the PPE is within the athlete's primary care physician's office; however, it acknowledges other approaches, including the coordinated medical team examination and, although not recommended, the locker room-based examination. As a consequence of the lack of mandates, many adolescents seek their PPEs with a variety of providers and may be diverted from a medical "home," where they can receive ongoing health immunizations and screening for the common psychosocial morbidities of adolescence.[59] The lack of continuity also precludes connection with the rehabilitative follow-up deemed essential to injury prevention.[60]

Finally, the PPE may not be able to meet criteria for an appropriate screening process, even if implemented perfectly, because it is neither sensitive nor specific enough to adequately detect the life-threatening medical conditions that are so exceedingly rare[60] or, in its current state, predict the potential for overuse injuries. Furthermore, as noted throughout this position statement, the evidence base is lacking as to which historical, anthropometric, and biomechanical findings confer increased musculoskeletal injury risk and which may be amenable to preventive interventions.

## Identification of Risk Factors

Little rigorous research has been conducted to investigate potential risk factors for overuse injuries in pediatric athletes. Table 2 lists a number of suspected growth-related intrinsic and extrinsic risk factors for overuse injuries, although these classifications and listings of risk factors are primarily based on anecdotal evidence.[9,61]

One group[10] attempted to identify accident-prone and overuse-prone profiles in young adults by prospectively investigating the effects of numerous physical and psychosocial characteristics on the rate of acute and overuse injuries. They developed an overuse-injury–prone profile for both males and females, which included physical factors such as a lack of stability (eg, decreased static strength coupled with laxity), muscle tightness, malalignment, more explosive strength, and large body size (ie, height and mass), and psychological traits including degree of carefulness, dedication, vitality, and sociability (Table 3).[10] Many of these characteristics (eg, anatomical

Table 2. Potential Risk Factors Predisposing Pediatric Athletes to Overuse Injuries[a]

| Growth-Related Factors | Intrinsic Factors | Extrinsic Factors |
|---|---|---|
| Cartilage at growth plate is more susceptible to injury | Previous injury | Training and recovery |
| Period of adolescent growth increases the risk of injury (eg, osteochondritis dissecans, apophysitis, physeal injuries) | Malalignment | Equipment |
| | Menstrual cycle | Poor technique |
| | Psychological issues | Psychological issues |
| | Muscle imbalances | Training errors |
| | Inflexibility | Environment |
| | Muscle weakness | Sport-acquired deficiencies |
| | Instability | Conditioning |
| | Level of play | |
| | Age | |
| | Height | |
| | Sex | |
| | Tanner stage | |
| | Laxity | |
| | Experience | |

[a] From DiFiori[9] and O'Connor et al.[61]

alignment, flexibility, strength, speed) can be measured during a PPE or baseline fitness test, allowing clinicians to identify athletes potentially at risk for overuse injuries and to develop preventive measures.

Not surprisingly, baseball has been the most widely studied youth sport in the United States. Lyman et al[18] prospectively evaluated 9- to 12-year-old baseball pitchers for pain or soreness in the shoulder or elbow during or after a pitching outing. Over 2 seasons, shoulder or elbow pain was noted in 47% (n = 141) of the pitchers, with most of the pain complaints considered mild (ie, without loss of time in games or practices). The authors also provided some associated pain-related factors that may be important in identifying those potentially at risk for subsequent overuse injuries. Elbow pain was related to increased age, decreased height, increased mass, increased cumulative pitch counts, arm fatigue, decreased self-perceived performance, participation in a concurrent weightlifting program, and participation in additional baseball leagues.[18] The presence of shoulder pain was associated with an increased number of pitches thrown in games, increased cumulative pitch counts, participating with arm fatigue, and decreased self-perceived performance. Both arm fatigue and self-perceived performance were risk factors for both elbow and shoulder pain. Therefore, pain should not be ignored, because it is often the first indicator of an overuse problem.[20] Rest should be incorporated in all programs; athletes who participated with arm fatigue were almost 6 times more likely to suffer from elbow pain and 4 times more likely to have shoulder pain that those who did not have arm fatigue.[18]

Table 3. Profiles of Overuse-Injury–Prone Male and Female Young Athletes[a]

| Males | Females |
|---|---|
| Tall stature | Tall stature |
| Endomorph body structure | Decreased upper extremity strength |
| Less static strength | Less static strength |
| More explosive strength | More explosive strength |
| Decreased muscle flexibility | High limb speed |
| High degree of ligamentous laxity | Increased muscle tightness |
| Large Q angle | Increased ligamentous laxity |
| | Greater leg-length discrepancy |
| | Pronation |
| | Large Q angle |

[a] From Lysens et al.[10]

A subsequent investigation[20] of 3 suspected risk factors (pitch type, pitch count, and pitching mechanics) found that the use of breaking pitches and high pitch counts increased the risk of both elbow and shoulder pain among youth pitchers. Specifically, the risk of elbow pain among pitchers using the slider increased 86% and the risk of shoulder pain in those throwing curveballs increased 52%. In addition, higher single-game pitch counts and higher cumulative (season-long) game pitch counts were associated with an increased risk of shoulder pain. This association between game pitch count and shoulder injury was strongest among 9- to 10-year-old and 13- to 14-year-old pitchers. Interestingly, pitching mechanics were not significantly associated with either elbow or shoulder pain in any of the age groups studied.[20] The authors[20] concluded that changeups remain the safest pitch for 9- to 14-year-olds to throw and that pitch limits, rather than inning limits, may be a better indicator of when pitchers should be removed from pitching to allow adequate rest.

More recently, Olsen et al[19] investigated risk factors for shoulder and elbow injuries in adolescent pitchers. Group analyses between pitchers with or without elbow or shoulder injury revealed that a greater percentage of injured pitchers started at another position before pitching, pitched with arm fatigue, and continued to pitch even with arm pain.[19] In addition, those who suffered an injury had a greater fastball speed and participated in a greater number of showcases (multiday, high-level events in which athletes may participate in numerous games within a short time span). A subsequent factor analysis revealed the following risk factors: participating in more than 8 months of competitive pitching (odds ratio [OR] = 5.05, 95% CI = 1.39, 18.32), throwing more than 80 pitches per appearance (OR = 3.83, 95% CI = 1.36, 10.77), having a fastball speed greater than 85 mph (136.8 kph) (OR = 2.58, 95% CI = 0.94, 7.02), and pitching either infrequently (OR = 4.04, 95% CI = 0.97, 16.74) or regularly (OR = 36.18, 95% CI = 5.92, 221.22) with arm fatigue.[19]

With respect to lower extremity injuries, few authors have attempted to identify specific overuse-injury risk factors in pediatric athletes, and their findings are inconclusive. These studies are limited to research on medial tibial stress syndrome (MTSS) and stress fractures.[30,62,63] In 2 investigations of risk factors for MTSS in high school cross-country runners, predictive variables differed.[62,63] One group[62] found that athletes with MTSS had a greater navicular drop (6.6 mm) than those who were asymptomatic (3.6 mm) and that the combination of navicular drop and sex accurately predicted 78% of MTSS cases. However, resting calcaneal position, tibiofemoral varum, and gastrocnemius length (ie, tightness) were not predictive. A subsequent investigation[63] revealed that sex and body mass index were predictors of MTSS, with the latter being the only predictor when controlling for orthotic use. Additionally, compared with those without an injury history, high school cross-country runners with a history of previous injury were 2 times more likely to report MTSS (OR = 2.18, 95% CI = 0.07, 6.4) and 3 times more likely to use orthotics (OR = 3.0, 95% CI = 0.09, 9.4).[63] Correlates of stress fractures in a general population of female adolescents have also been researched and, although age had the strongest association with a stress-fracture history (27% to 29% increased odds for each year beyond age 11), participation in more than 16 hours per week of vigorous activity (OR = 1.88, 95% CI = 1.18, 3.03) and in high-impact physical activity, such as basketball, soccer, volleyball, running, tennis, or cheerleading (OR = 1.06, 95% CI = 1.03, 1.10), was also related to stress-fracture history.[30] They reported a slight (but nonsignificant) increased risk for stress fracture in the most sedentary girls, a reminder that participation in impact-loading physical activity is important in this population because of its positive effects on bone mineral density.[30]

In a subsequent clinic-based study of adolescent female athletes, only family history of osteoporosis or osteopenia was associated with stress fracture (OR = 2.96, 95% CI = 1.36, 6.45).[64] However, in neither adolescent athlete investigation was stress fracture associated with irregular menstrual periods, as has been demonstrated in adult women athletes and military recruits.[65] In combination, these investigations may begin to identify safe thresholds for participation in vigorous physical activity (16–20 h/wk). They also suggest that risk stratification must incorporate both intrinsic (eg, inherited skeletal quality) and extrinsic (eg, training volume) factors. Another area of focus concerning risk factors has been generalized joint hypermobility, which is characterized by mobility of multiple joints beyond the normal range of motion. Community prevalence of generalized joint hypermobility appears to depend on age, sex, and race, with reports ranging from 2% (adult Caucasian males) to 57% (African females of mixed ages).[66] A considerable number of studies of rheumatology and pediatric clinic-based populations appear to demonstrate relationships between generalized joint hypermobility and insidious-onset arthralgia and fibromyalgia.[67–75] Yet prospective studies of nonclinic populations are at best inconclusive as to whether joint hypermobility increases injury risk.

In a prospective study[23] of 17-year-old military recruits, those with hypermobility had more injuries during boot camp than those who were not hypermobile. Another prospective study[24] of youngsters 6 to 14 years old demonstrated that children with hypermobile joints had more complaints of joint pain than nonhypermobile children. A retrospective study[76] of pediatric (aged 6–16 years) netball players in Australia showed that hypermobility was associated with an increased prevalence of self-reported injuries. In another small retrospective study[77] including children and adults, more injuries were reported by hypermobile ballet dancers than by their nonhypermobile counterparts. In an attempt to describe overuse-prone profiles of young adults, Lysens et al[10] reported that males and females with weak muscles, poor flexibility, and hypermobility may be at increased risk for overuse injuries.

Alternately, several prospective studies of mixed (child and adult) or adult athletic populations do not support the conclusion that joint hypermobility is related to injury risk. A prospective study[78] of netball players aged 15 to 36 years demonstrated no differences in injuries based on hypermobility status. Studies of National Collegiate Athletic Association lacrosse players[79] and professional soccer players[80] also have indicated no differences in injuries based on hypermobility status. Finally, a retrospective study[81] of female gymnasts aged 10 to 21 years found no relationship between hypermobility status and reported history of injuries.

Screening for generalized joint hypermobility is relatively easy using the methods first proposed by Carter and Wilkinson[82] and later modified by Beighton and Horan.[83] This multijoint active range-of-motion screening procedure is widely accepted (Table 4). Incorporating this screening into the PPE might add only a few minutes to each assessment, but its use should depend upon the time, cost, and level of experience of the examiner administering the PPE.

### Proper Supervision and Education

Organizations sponsoring interscholastic or club-based athletics in which pediatric athletes participate have the responsibility to ensure adequate coaching and medical supervision.[5,13,14] Proper supervision by coaches and enforcement of the rules of the sport (which includes adequate education of both coaches and officials) may serve as a means to decrease overuse injury risk in this age group.[9,15,50] For example, Little League Baseball provides pitch-count regulation (Appendix A), tracking sheet (Appendix B), and pitching eligibility forms, all of which are easily accessible to youth baseball coaches. The guidelines mandating pitch-count limits are adapted from scientific evidence and are updated frequently as new research emerges.[84] Moreover, proper medical supervision at competitions and practices may allow for early recognition of overuse injuries in the beginning stages to permit proper evaluation, referral, and rehabilitation before they result in time lost from participation.[14,15]

Education of all athletes, parents, coaches, and officials regarding overuse injuries and preventive mechanisms is advocated. Athletes, parents, and coaches should all have knowledge of general signs and symptoms of overuse, including but not limited to a gradual onset of pain, pain presenting as an ache, no history of direct injury, stiffness or aching after or during training or competition, increasing periods of time for pain to resolve, point tenderness, visible swelling, missed training sessions as a result of the pain or injury, and a problem that persists.[25]

**Table 4. The Beighton and Horan Joint Mobility Index[a]**

| Test | Description | Scoring[b] |
|---|---|---|
| Wrist flexion, thumb opposition | Stabilize the distal portion of the forearm. The thumb being tested is passively abducted by the fingers of the opposite hand toward the volar aspect of the forearm with the wrist in flexion. | Score 1 point for each thumb that can be passively bent to touch the forearm. |
| Fifth metacarpal extension | The patient sits with the arm in 80° of abduction and the elbow flexed to 90°. The forearm rests on the table in a pronated position. The fifth metacarpal is extended. | Score 1 point for each metacarpal that extends past 90°. |
| Elbow extension | The patient sits with the shoulder flexed to 90° and the forearm supinated. | Score 1 point for each elbow that can actively hyperextend past 0°. |
| Trunk and hip flexion | The patient stands and then flexes at the waist, attempting to touch the palms flat to the floor while keeping the knees either extended or hyperextended. | Score 1 point if the patient can bend at the waist and place the hands flat on the floor without bending the knees. |
| Knee extension | The patient lies supine with 1–2 towels placed under the ankles. | Score 1 point for each knee that can passively hyperextend past 0°. |

[a] From Carter and Wilkinson[82] and Beighton and Horan.[83]
[b] Total possible points = 9.

These signs and symptoms should not be ignored as "growing pains" but should be taken seriously by the athlete, parent, and coach. Athletes involved in running-based sports should be educated regarding sensible training habits and the proper fit and selection of running shoes to reduce impact forces. Athletes involved in throwing sports should be educated as to the potential risk factors for upper extremity overuse injuries, with specific emphasis on using arm fatigue as an indicator to stop throwing.[18,19] All athletes should be educated on proper exercise progression and should gradually increase time, distance, and intensity by the 10% rule (see "Training and Conditioning" section below).[57]

To our knowledge, no published studies have addressed the general knowledge of overuse injuries among coaches; however, reports describe the general lack of first aid, injury recognition, and management knowledge of high school[26] and youth[27] coaches. No mandated national coaching education program exists in the United States for youth sports, and the requirements for high school athletic coaches vary from state to state, with some requiring only first aid and cardiopulmonary resuscitation (CPR) certification. However, numerous coaching education programs provide information related to proper biomechanics of sporting skills, nutrition, physical conditioning, development of athletes, and prevention, recognition, and management of injuries (Table 5). Completion of at least 1 of these courses is recommended for all coaches working with pediatric athletes. Additionally, coaches should be encouraged to maintain their certifications and participate in continuing education opportunities to remain current with the latest sports safety information.

## Sport Alterations

Alterations or modifications to the existing rules for adults may prevent overuse injuries in children and adolescents.[5,13,31] These modifications may be simple, including shorter quarters or halves, bases closer together,

**Table 5. Coaching Education Programs**

| Organization | Training Focus | Format | Web Address |
|---|---|---|---|
| National Athletic Trainers' Association Sports Safety for Youth Coaches | Recognition of illnesses and injuries, safe playing conditions, training and conditioning, emergency planning | Online | http://www.nata.org |
| National Youth Sports Coaches Association | General youth sports<br>Sport-specific training | Online | https://www.nays.org/onlinepromo/OnlineHome.html |
| American Sports Education Program | Technical and tactical skills of sport<br>Cardiopulmonary resuscitation, automated external defibrillator certification, coaching essentials, and sports first aid courses | Online | http://www.asep.com/ |
| National Center for Sports Safety (PREPARE) | Sports safety that teaches participants to recognize and prevent common athletic injuries, emergency preparedness, first aid management, and sport enjoyment | Online | http://www.sportssafety.org/prepare/ |
| American Red Cross | Environmental hazards, emergency situations, and decision making for first aid care | Classroom | http://www.redcross.org/services/hss/courses/sports.html |
| National Federation of State High School Associations | "Fundamentals of Coaching" course | Online | http://www.nfhslearn.com/CourseDetail.aspx?courseID=1000 |
| | Online first aid course | | http://www.nfhslearn.com/CourseDetail.aspx?courseID=1001 |

Table 6. Recommendations for Pitch Counts on the First 4 Days After a Pitching Event[a]

| | Pitch Count | | | |
|---|---|---|---|---|
| Age, y | 1 d Rest | 2 d Rest | 3 d Rest | 4 d Rest |
| 9–10 | 21–33 | 34–42 | 43–50 | 51+ |
| 11–12 | 27–34 | 35–54 | 55–57 | 58+ |
| 13–14 | 30–35 | 36–55 | 56–69 | 70+ |
| 15–16 | 30–39 | 40–59 | 60–79 | 80+ |
| 17–18 | 30–39 | 40–59 | 60–89 | 90+ |

[a] From Andrews and Fleisig.[21] Reprinted with permission from USA Baseball.

less frequent games or practices, or pitch-count limits; or they may be more complex, such as the recommendation to match athletes by height, maturity, or skill as opposed to age.

Some experts are now moving away from the long-held and perhaps largely anecdotal belief that throwing breaking pitches is related to arm injuries in young baseball players. The only prospective study[20] we were able to find appears to support this belief: pitchers throwing sliders had an 86% increased risk of elbow pain, and pitchers throwing curveballs had a 52% increased risk of shoulder pain. However, biomechanical studies comparing torque and moments generated by different types of pitches in 11- to 14-year-olds[85] and 14- to 18-year-olds[86] showed that the fastball imposed more demand than the curveball. Based on the results of these biomechanics studies, some researchers have postulated that throwing breaking pitches is not necessarily risky for young athletes. Yet it is important to recognize that the participants in these studies were healthy, with no history of arm injury, and, in the case of the Nissen et al[86] study, perhaps slightly older than the players who are generally the target of the recommendation against throwing breaking balls.

Furthermore, pitching limits should be established for 9- to 14-year-olds, with full-effort (ie, competition) throwing limited to 75 pitches per game and 600 pitches per season.[20] Young throwers should also have adequate rest after a pitching event and adjust pitch limits for those rest days accordingly (Table 6). Table 7 lists baseball-pitcher–specific modification recommendations.

Table 7. Suggested Sport-Modification Recommendations for Adolescent Pitchers[a]

1. Avoid pitching with arm fatigue.
2. Avoid pitching with arm pain.
3. Avoid pitching too much. Future research needed, but the following general limits are
   a. Avoid pitching more than 80 pitches per game.
   b. Avoid competitive pitching more than 8 months of the year.
   c. Avoid pitching more than 2500 pitches in competition per year.
4. Pitchers with the following characteristics should be monitored closely for injury
   a. Those who regularly use anti-inflammatories to "prevent" injuries
   b. Regularly starting pitchers
   c. Pitchers who throw > 85 mph (137 kph)
   d. Taller and heavier pitchers
   e. Pitchers who warm up excessively
   f. Pitchers who participate in showcases

[a] Olsen SJ II, Fleisig GS, Dun S, Loftice J, Andrews JR, *American Journal of Sports Medicine*, 905–912, copyright ©2006 by SAGE Publications. Reprinted by permission of SAGE Publications.

In addition to Little League, other athletic governing bodies and organizations have instituted sport modifications. The US Cycling Federation has imposed gear-ratio limits for athletes between 10 and 16 years of age,[54] limiting the maximal stress or effort in those at the lower end of that age range. Running organizations in Australia also have age-related regulations, including set distances in which younger athletes may participate. Adolescents can begin participating in 5-km (3.1-mile) races at age 12 and in 10-km (6.2-mile) races at age 14. Half-marathon (21.1-km; 13.1-mile) and marathon (42.2-km; 26.2-mile) distances can be run beginning at ages 15 to 16 and >18 years, respectively.[54] As described in Table 8, USA Swimming has recommendations for the number of sessions per week and the length of each session for various levels of competitive age-group swimming.[87]

## Training and Conditioning

Proper training and conditioning, both before and during the season, may prevent overuse injuries. Unfortunately, in today's society, many youngsters are not as active as previous generations, leading to a phenomenon of cultural deconditioning.[88,89] There has been a general decline in physical activity, including free play, walking to school, and regular physical-education classes, with a concurrent increase in sedentary activities, including watching television, playing video games, and, in some cases, physical activity limited to sport participation. Athletes with poorer levels of general fitness or conditioning may not be able to tolerate the demands of training required for sport participation. Therefore, all pediatric athletes should begin by establishing a good general-fitness routine that encompasses strengthening, endurance, and flexibility.[5,9,37] Sufficient participation in general strength, endurance, and flexibility training, as well as lifestyle physical fitness (eg, taking the stairs instead of the elevator), should precede sport-specific training.[38] Once a general foundation of fitness has been established, athletes should begin to gradually increase their training loads. Pediatric athletes are advised to follow the 10% rule, which allows for no more than a 10% increase in the amount of training time, distance, repetitions, or load each week.[5,31] For example, a runner who is currently running 15 miles/wk (24 km/wk) should only be allowed to increase mileage to 16.5 miles (27 km) the following week. Similarly, athletes participating in strength training should increase only either repetitions or weight by 10% each week, not both. The goal of the 10% rule is to allow the body to adjust gradually to increased training intensity.

**Table 8. Developmental Progression for Pediatric Swimmers[a]**

| Level | Category | Commitment |
|---|---|---|
| 1 | Sport preparation: ages 6–9 y | 2–3 sessions/wk<br>30–60 min/session |
| 2 | Basic skill development: ages 8–11 y | 2–4 sessions/wk<br>30–60 min/session<br>Encourage other activities, sports<br>Intrasquad or low-pressure competition |
| 3 | Basic training development: ages 11–14 y | 4–6 sessions/wk<br>60–90 min/session<br>Year-round participation<br>Encourage other activities, sports while understanding the need to meet attendance expectations |
| 4 | Progressive training: ages 13–18 y | 6–10 sessions/wk<br>90–120 min/session<br>Year-round competition<br>Including long-course (50-m pool-length) competition<br>Commit to swimming<br>Shorter breaks to minimize deterioration of aerobic base |
| 5 | Advanced training: age 14 y and older | 8–10 sessions/wk<br>90–120 min/session<br>Year-round<br>High commitment level<br>Short breaks to minimize deterioration of aerobic base |

[a] Reprinted with permission from USA Swimming.[87]

More recently, preventive training programs have been targeted specifically at the pediatric athlete. Although the primary focus of many of these programs has often been for the prevention of noncontact anterior cruciate ligament injuries, several authors[34–36] have also investigated whether overuse-injury risk could be reduced among program participants. In a prospective study of a structured warm-up program including technique training, neuromuscular control, and balance and strengthening exercises, Olsen et al[36] reported that participants had a reduction in overall injuries (RR = 0.49, 95% CI = 0.36, 0.68), lower limb injuries (RR = 0.51, 95% CI = 0.36, 0.74), and overuse injuries (RR = 0.43, 95% CI = 0.25, 0.75). Similarly, a program that focused on educating and training coaches to incorporate an overall-prevention mentality (consisting of improved warm-up, cool-down, taping unstable ankles, rehabilitation, promoting fair play, and a set of 10 exercises designed to improve joint stability, flexibility, strength, coordination, reaction time, and endurance) resulted in a reduction in both total injuries (0.76 ± 0.89 versus 1.18 ± 1.04, $P < .01$) and overuse injuries (0.26 ± 0.48 versus 0.44 ± 0.65, $P < .05$) per player-year.[35] Specific to physically active adolescents, a 6-month, home-based balance-training program resulted in improvements in both static and dynamic balance among program participants.[34] However, because of the limited number of injuries reported, no conclusions regarding the effectiveness of the program on reducing injuries could be drawn. Still, a clinically important difference was noted in self-reported injuries: program participants reported 3 (95% CI = 5, 35) injuries per 100 adolescents, compared with 17 (95% CI = 3, 24) in the control groups. Interestingly, the program was more effective in reducing injuries among those adolescents who reported sustaining an injury in the previous year,[90] thus highlighting the need to identify injury history through a thorough PPE. In general, programs that are successful in reducing the risk of overuse injuries among pediatric athletes seem to include strengthening, neuromuscular control, flexibility exercises, balance, and technique training.

## Delayed Specialization

One of the more controversial areas with respect to pediatric overuse injuries deals with the early specialization of athletes participating in the same sport year-round from a young age. Although little evidence-based research demonstrates that this practice has negative consequences on physical growth or psychological outcomes, many clinicians and health care organizations have advocated for diversity in sport participation or delayed specialization.[5,9,91,92,93] It is theorized that participation in only 1 sport can result in increased risk for repetitive microtrauma and overuse[5] or that multisport athletes who do not obtain adequate rest between daily activities or between seasons and those who participate in 2 or more sports that emphasize the same body part are at higher risk for overuse injuries than those in multiple sports with different emphases.[31]

Young athletes who participate in a variety of sports tend to have fewer injuries and play longer, thereby maintaining a higher level of physical activity than those who specialize before puberty.[92] In addition to the potential for repetitive microtrauma and overuse injury, specialization in 1 sport may be associated with nutritional and sleep inadequacies, psychological or socialization issues, and ultimately burnout. These problems might be avoided with a balanced lifestyle and a strong support system made up of parents, friends, coaches, and health care providers.[12]

## CONCLUSIONS

The major objective in managing repetitive or training injuries in athletes of any age should be to determine risk factors for injury and identify steps to prevent the occurrence of these injuries. Knowledge is growing about risk factors for the occurrence of both acute traumatic injuries and repetitive microtrauma overuse injuries in adults, particularly in such activities as military training, work activities, and sports. However, too little is known about risk factors for overuse injury in pediatric athletes.

Injury surveillance in young athletes should be improved to record the occurrence of injury and the determination of associated risk factors, as well as epidemiologic data (eg, age, sex, height, mass, and, if possible, Tanner stage). Epidemiologic studies in specific environments in pediatric populations would add greatly to the understanding of the risk associated with particular sport activities, thus providing a foundation for future studies of prevention and treatment efficacy.

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## DISCLAIMER

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Appendix A. Little League Pitch Count Tracker. Form provided by Little League International, Williamsport, PA.

## ______________ Little League -- Baseball Game Pitch Log

**Team** ______________ **Opponent** ______________ **Date** ______________

| Pitcher's Name | Uniform Number | League Age | X Cross out the number as that pitch is thrown. O Circle the number for the last pitch thrown in each half-inning. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| | | | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 |
| | | | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| | | | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 |
| | | | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| | | | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 |
| | | | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| | | | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 |
| | | | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| | | | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 |
| | | | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| | | | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 |
| | | | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| | | | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 |
| | | | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| | | | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 |
| | | | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| | | | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 |
| | | | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 |
| | | | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 |
| | | | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 |

Pitching eligibility varies by the league age of the pitcher, which is the pitcher's age as of May 1 of the current year. The pitching eligibility regulation is Regulation VI (see current rule book for details). A blank electronic version of this form is available for free download at www.littleleague.org.

Appendix B. Little League Pitcher Eligibility Tracker. Form provided by Little League International, Williamsport, PA.

# ____________________ Little League -- Baseball Pitcher Eligibility Tracking Form

## Division ____________________ Team ____________________

| Date of Game | Pitches Thrown | Pitcher's Name | Unif. No. | League Age | Tm. Manager's Signature * | Opp. Manager's Signature * | Scorekeeper/Ump Signature * | Eligible to pitch again on (date) |
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Pitching eligibility varies by the league age of the pitcher, which is the pitcher's age as of May 1 of the current year. The pitching eligibility regulation is Regulation VI (see current rule book for details). An electronic version of this form is available for free download at www.LittleLeague.org.

* Note: These signatures may be optional as determined by the local league.

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