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original research

Electromyography of 3 Scapular Muscles: A Comparative Analysis of the Cuff Link Device and a Standard Push-Up

W. Steven Tucker, MS, ATC*; Brian M. Campbell, PhD†; Erik E. Swartz, PhD, ATC‡; Charles W. Armstrong, PhD*

*University of Toledo, Toledo, OH; †Bowling Green State University, Bowling Green, OH; ‡University of New Hampshire, Durham, NH

Context: The Cuff Link is a closed kinetic chain rehabilitation apparatus for the upper extremity. Limited research has established its effectiveness to elicit muscle activation of the scapular muscles.

Objective: To determine if scapular muscle activation differs in response to 2 upper extremity closed kinetic chain exercises: Cuff Link and standard push-up.

Design: A single-group, repeated-measures design.

Setting: Controlled laboratory.

Patients or Other Participants: Twenty-eight healthy individuals (13 women: age = 19.69 ± 1.55 years, height = 167.44 ± 9.52 cm, mass = 61.00 ± 8.79 kg; 15 men: age = 22.00 ± 3.91 years, height = 181.44 ± 6.60 cm, mass = 82.36 ± 13.23 kg) with no history of shoulder or low back injury volunteered to participate in this study.

Intervention(s): Participants performed 10 trials of complete revolutions on the Cuff Link and 10 full–weight-bearing push-ups. We controlled trial velocity and randomized order. Trunk and shoulder positions were normalized to the participant's height. Using surface electromyography, we recorded muscle activity of the serratus anterior, middle trapezius, and lower trapezius. Rectified and smoothed electromyography data for the serratus anterior, middle trapezius, and lower trapezius were normalized as a percentage of the maximal voluntary isometric contractions (%MVIC).

Main Outcome Measure(s): Mean muscle activity of the serratus anterior, middle trapezius, and lower trapezius. We used paired-samples *t* tests to analyze the mean data for each condition. The α level was adjusted to .016 to avoid a type I error.

Results: Middle trapezius %MVIC was greater during push-ups (27.01 ± 20.40%) than during use of the Cuff Link (11.49 ± 9.46%) ($P = .001$). Lower trapezius %MVIC was greater during push-ups (36.07 ± 18.99%) than during use of the Cuff Link (16.29 ± 8.64%) ($P = .001$). There was no difference in %MVIC for the serratus anterior between conditions.

Conclusions: The push-up demonstrated greater middle trapezius and lower trapezius activation levels compared with the Cuff Link. However, the push-up had a high participant failure rate. Because serratus anterior activation levels were similar, the Cuff Link may be an appropriate alternative for individuals lacking the upper body strength to perform a push-up.

Key Words: scapula, rehabilitation, closed kinetic chain exercises

Key Points

- Muscle activation of the middle trapezius and lower trapezius was greater during a push-up than during use of the Cuff Link.
- Muscle activation of the serratus anterior was not greater during use of the Cuff Link than during the push-up.
- Based on the serratus anterior muscle activation levels, both the Cuff Link and push-up exercises may be beneficial to healthy individuals who participate in overhead activities and are susceptible to shoulder impingement syndrome.
- The Cuff Link exercise may be an appropriate alternative for individuals who need an upper extremity closed kinetic chain exercise with high levels of serratus anterior activation but lack sufficient upper body strength to perform a standard push-up.
- When higher activation levels of the serratus anterior, middle trapezius, and lower trapezius are needed, the standard push-up is a more advantageous exercise than the Cuff Link exercise.

The prevalence of shoulder disorders and the need for rehabilitation has led to high health care costs for patients. Approximately 13.7 million people in the United States seek treatment from a physician for a shoulder problem each year.[1] Sprain or strain is diagnosed in 3.7 million of those patients,[1] who need effective rehabilitation protocols so they can return to work or physical activity.

The use of closed kinetic chain exercise is a strategy incorporated into the rehabilitation protocols of patients with shoulder disorders. Defined as any activity that occurs about a distally fixed segment, such as a foot or hand, closed kinetic chain exercises often require weight bearing.[2] Clinicians and researchers recognize the benefits of closed kinetic chain exercise for the upper extremity.[3–10] Equal distribution of compression and shear force is evident at 90° of shoulder elevation, which is an ideal position for stabilization of the glenohumeral joint.[11–14] Researchers have demonstrated that training with closed kinetic chain exercises in which the glenohumeral joint is elevated to approximately 90° improves proprioception and neuromuscular control of the shoulder complex in healthy individuals.[15,16]

Many authors consider the serratus anterior to be the primary stabilizer of the scapula[17,18] because a large moment arm gives it the greatest mechanical advantage during upward rotation.[19] Research has linked shoulder disorders in athletes and nonathletes to weakness in the serratus anterior.[20–23] Therefore, clinicians have placed increased emphasis on the inclusion of the serratus anterior in prevention and rehabilitation protocols for the upper extremity. However, the serratus anterior is often difficult to activate in a controlled clinical setting.

The push-up is a closed kinetic chain exercise for the upper extremity that has been investigated extensively.[7,17,24–28] Considerable amounts of serratus anterior activation have been reported during the push-up and variations of the push-up, such as the push-up with a plus.[17,25,27,28] Because of the position of the glenohumeral joint, as well as the static and dynamic stabilization of the shoulder complex, the push-up may be clinically beneficial in eliciting muscle activation. However, because of the upper body strength required to perform it, the push-up is not a practical rehabilitation exercise for all clinical populations. Therefore, further research investigating other upper extremity closed kinetic chain exercises with similar or greater benefits to the scapular muscles is needed.

The Cuff Link (efi Sports Medicine, San Diego, CA) is an upper extremity closed kinetic chain rehabilitation apparatus with limited research to validate its effectiveness as a rehabilitation tool and no comparative analyses with other validated forms of rehabilitation. According to the manufacturer, the Cuff Link is intended to increase dynamic stabilization of the muscles that act on the glenohumeral and scapulothoracic joints, as well as trunk stabilization. Researchers have determined that increasing the amount of weight bearing on the Cuff Link elicits increased muscle activation of the serratus anterior, anterior deltoid, pectoralis major, and upper trapezius.[29]

The purpose of our study was to compare the amount of muscle activation of 3 scapular muscles (serratus anterior, middle trapezius, and lower trapezius) during use of the Cuff Link and during a standard push-up. We hypothesized that (1) muscle activation in the middle trapezius and lower trapezius would be greater during the push-up than during use of the Cuff Link, and (2) muscle activation in the serratus anterior would be greater during use of the Cuff Link than during the push-up.

METHODS

Research Design

The study was conducted in a controlled laboratory setting with all participants performing both Cuff Link and push-up conditions. For this single-group, repeated-measures design, the independent variable was condition (Cuff Link and push-up), and the dependent variable was the activation of the 3 muscles (serratus anterior, middle trapezius, and lower trapezius).

Participants

Upon approval by the institutional review board for the testing of human participants at the University of Toledo, 34 healthy men and women aged 18 to 35 years were recruited from a sample of convenience to participate in this study. Of the 34 participants recruited, 28 participants successfully completed the testing procedures (13 women: age = 19.69 ± 1.55 years, height = 167.44 ± 9.52 cm, mass = 61.00 ± 8.79 kg; 15 men: age = 22.00 ± 3.91 years, height = 181.44 ± 6.60 cm, mass = 82.36 ± 13.23 kg). Participants were physically active individuals who were not currently enrolled in a training program and who were not competitive athletes. Participants rated their activity level on a scale of 0 to 5. Five represented a very active lifestyle consisting of 20 minutes of physical activity at least 5 days per week, and 0 represented a sedentary lifestyle consisting of no physical activity. The average value of activity level was similar for men (3.47 ± 1.13) and women (3.62 ± 0.96).

All participants provided informed consent and were selected at random without regard for sex, race, or ethnicity. Participants completed a medical history form before the study. Any person with a history of significant shoulder injury was excluded from participation. Significant injury was defined as dislocation, subluxation, surgical procedure, labrum tear, chronic bursitis, or a sprain or strain that prevented the individual from performing activities of daily living for more than 3 days. Any person who was being treated for a heart condition, respiratory condition, high blood pressure, or chronic illness and any woman who was or could possibly be pregnant at the time of the study also were excluded from participation.

Instrumentation

Activation of the 3 muscles was analyzed using the TeleMyo 2000 electromyography (EMG) system (Noraxon USA Inc, Scottsdale, AZ). The EMG signal was telemetered to a receiver that contained a differential amplifier with an input impedance of 10 MΩ and a common mode rejection ratio of 130 dB. An amplifier gain of 1000 was used, and the signal-to-noise ratio was less than 1 μV RMS of the baseline. The EMG signals were filtered with a band-pass Butterworth filter at 15 Hz and 500 Hz. The receiver was interfaced with a Latitude C840 computer (Dell, Round Rock, TX). Data collection was performed using 9-mm pregelled bipolar Ag/AgCl disposable electrodes (part ED3000ZT; Danlee Medical Products Inc, Syracuse, NY). A DCR-TRV 140 Digital 8 Handycam (Sony Corp, Tokyo, Japan) was used in conjunction with MyoVideo (version 1.5.03; Noraxon USA Inc) and allowed for time matching of EMG data to events of interest from the recorded activity. A sampling rate of 1000 Hz was used for data collection. Electromyography files were stored on the computer's hard drive and copied to MyoResearch (version 2.11; Noraxon USA Inc) for data processing and analysis.

The Cuff Link consists of a 56-cm diameter circle with a crossbar extending its width (similar to a steering wheel). The Cuff Link contains 5 insertion holes (1 center hole, 2 holes that are 15 cm apart and 2 holes that are 48 cm apart) for placement of 3 types of handles: 90° flexed elbow, extended elbow, and deviated wrist. The manufacturer refers to the 90° flexed-elbow handles as the "scapular isolators." Therefore, the 90° flexed-elbow handles were used at the 48-cm insertion holes for this study. The 90° flexed-elbow handles measure 30 cm in

Figure 1. Position of the Cuff Link condition.

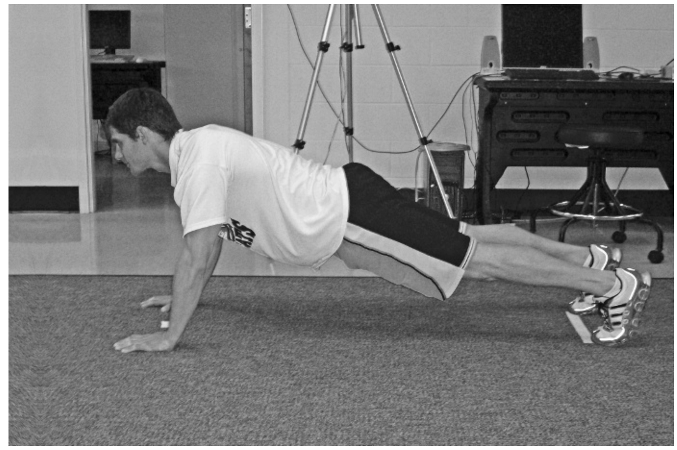

Figure 2. Position of the push-up condition.

length and 7 cm in height. The Cuff Link also includes 2 half-sphere center axes, 4 cm and 5 cm in height. For this study, the 5-cm center axis was used.

Procedures

To warm up, each participant rode a stationary bicycle for 10 minutes. Next, the participant's skin was prepared by shaving, abrading, and cleaning with a cotton ball soaked in a 70% isopropyl alcohol solution. A pair of surface EMG electrodes were placed side by side on the right side of the body over the muscle bellies of 3 selected muscles (serratus anterior, middle trapezius, and lower trapezius).[30] The interelectrode distance was 2 cm, and a reference electrode was placed on the proximal one-third of the tibia. Participants then performed 3 trials of a maximal voluntary isometric contraction (MVIC) against manual resistance from the primary investigator for each of the 3 muscles. We chose the positions for MVIC trials because standard muscle-testing techniques indicated that they best isolated the activation of individual muscles.[31,32]

Before data collection, participants were allowed adequate time to practice each MVIC position. The serratus anterior was tested with the participant seated on a treatment table without back support and the shoulder internally rotated and abducted to 125° in the scapular plane while resistance was applied proximal to the participant's elbow. The middle trapezius was tested with the participant lying prone on a treatment table and the shoulder externally rotated and horizontally abducted to 90° while resistance was applied distal to the participant's elbow. With the participant lying prone, the lower trapezius was tested with the shoulder in external rotation and the arm overhead and lined up with the muscle fibers of the lower trapezius while resistance was applied distal to the elbow.[31] Each trial was a 5-second isometric contraction, and participants rested for 30 seconds between trials. To promote maximal effort, the primary investigator provided oral encouragement to the participants.

After collection of the MVIC data, participants were familiarized with the conditions associated with the study. Before the practice session, the primary investigator calculated 75% of the participant's total height. This percentage was used to normalize the testing procedure across participants by establishing a standardized distance between foot and hand placements for the Cuff Link and push-up conditions.[29] The primary investigator marked the floor for hand placement (push-up condition) or center axis of the Cuff Link (Cuff Link condition) and for foot placement in both conditions. The primary investigator also demonstrated and instructed the participants on the Cuff Link and push-up conditions. Participants practiced until they felt comfortable performing the 2 conditions and until they performed to the primary investigator's satisfaction. A 10-minute rest period followed the practice session.

For the Cuff Link condition, participants performed 10 separate revolutions on the Cuff Link in the full–weight-bearing position (Figure 1) and rested for 1 minute between revolutions. One Cuff Link revolution consisted of making contact with the ground with all edges of the Cuff Link in a clockwise motion. Velocity of each revolution was controlled using a metronome set at 60 beats per minute, and participants were instructed to complete each revolution in 2 seconds.

For the push-up condition, the participant performed 10 separate repetitions of a standard push-up (Figure 2) and rested for 1 minute between repetitions. Hand placement was standardized at 48 cm apart because this was the same distance between the handle positions of the Cuff Link. One push-up repetition included both the concentric and eccentric phases of the push-up. Participants started with their elbows in terminal extension. During the eccentric phase of the push-up condition, participants lowered their bodies by means of elbow flexion until their trunks reached a 7-cm block resting on the floor. The block was located at the midline of the body and was 10 cm inferior to the hand placement. Immediately after contact with the block, participants began the concentric phase of the condition, returning to the starting position by performing elbow extension. Each phase lasted 1 second, and the entire repetition lasted 2 seconds. Again, a metronome set at 60 beats per minute was used to control velocity.

For both the Cuff Link and push-up conditions, a condition was completed after 10 successful trials were recorded. Trials that did not meet protocol were deemed unsuccessful by the primary investigator and were replaced with a successful trial for data analysis. A trial was deemed unsuccessful if the investigator considered it too fast or too

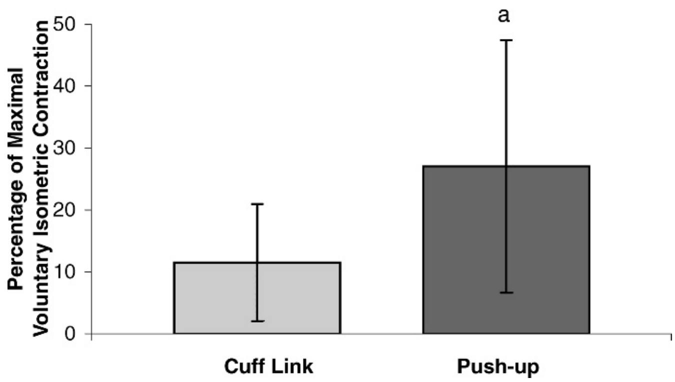

Figure 3. Electromyography results for the middle trapezius as a percentage of the maximal voluntary isometric contraction. [a] Indicates $P \leq .001$.

slow, if all edges of the Cuff Link did not come into contact with the ground, or if the trunk did not contact the 7-cm block during the push-up.

Data Processing

Using MyoResearch, raw EMG data were full-wave rectified and smoothed using a moving window (50 ms) with a linear algorithm. The middle 3 seconds of the MVICs were used for data analysis, allowing participants 1 second to reach full muscle activation and eliminating the potential effects of fatigue during the last second. For each participant, the mean EMG data for the MVIC trials for each of the 3 muscles were averaged. We then averaged the EMG data for the 3 muscles during the 10 Cuff Link and 10 push-up trials. The mean EMG data for the 3 muscles from the Cuff Link and push-up trials were normalized as a percentage of the MVIC (%MVIC). Data were exported to Excel (version 2003; Microsoft Corp, Redmond, WA) and imported to SPSS (version 11.0 for Windows; SPSS Inc, Chicago, IL).

Statistical Analysis

For each dependent variable, the mean data of 10 successful trials for each condition (Cuff Link and push-up) were analyzed using paired-samples *t* tests (condition × muscle activation) for comparisons of the 2 conditions across the 3 muscles (serratus anterior, middle trapezius, and lower trapezius). To avoid a type 1 error, the α level was adjusted to .016. Statistical analysis was performed with SPSS.

RESULTS

Of the 34 participants recruited, 6 participants were excluded from the study, resulting in an 82% completion rate. Five participants (1 man, 4 women) were unable to successfully perform the push-up protocol. Note that all 5 of these participants were able to successfully complete the Cuff Link protocol with minimal effort. Another participant (1 woman) was excluded before participation because of a previously undiagnosed medical condition.

The muscle activation of the middle trapezius during the push-up (27.01 ± 20.40%, SE = 3.86%) was higher ($t_{1,26}$ = 30.32, P = .001) than the activation during use of the Cuff Link (11.49 ± 9.46%, SE = 1.79%) (Figure 3). The results of the paired-samples *t* test for the lower trapezius also revealed a difference ($t_{1,26}$ = 35.584, P = .001), with the push-up eliciting higher muscle activation levels (36.07 ± 18.99%, SE = 3.59%) compared with the Cuff Link (16.29 ± 8.64%, SE = 1.63%) (Figure 4). During the Cuff Link condition, the serratus anterior had a muscle activation level of 74.56 ± 39.99% (SE = 7.56%), and the push-up condition resulted in a level of 68.45 ± 32.84% (SE = 6.21%) (Figure 5). The results of the paired-samples *t* test for serratus anterior muscle activation did not indicate a difference ($t_{1,26}$ = 2.247, P = .159) between the 2 conditions.

DISCUSSION

The results of this study supported our first hypothesis that muscle activation in the middle trapezius and lower trapezius would be greater during a push-up than during use of the Cuff Link. Contrary to our second hypothesis, muscle activation of the participants' serratus anterior was not greater during use of the Cuff Link than during the push-up. Therefore, the push-up may be a more advantageous therapeutic exercise when high levels of serratus anterior, middle trapezius, and lower trapezius activation are desired. Despite our testing of a healthy participant population, the push-up was a more difficult exercise to perform compared with the Cuff Link, especially among women. Therefore, for certain clinical populations that want an upper extremity closed kinetic chain exercise with high levels of serratus anterior activation, the Cuff Link may be a less physically demanding task to perform.

Patients with shoulder impingement syndrome often demonstrate an overactive upper trapezius and a suppressed serratus anterior.[20,21,33,34] The muscle-force imbalance between the upper trapezius and serratus anterior causes abnormal superior translation of the scapula and decreased upward rotation efficiency.[27] Based on the serratus anterior muscle activation levels, both the Cuff Link and push-up appear to benefit healthy individuals who participate in overhead activities and are susceptible to shoulder impingement syndrome. Additionally, research has indicated that the activation level of the upper trapezius is relatively low during the Cuff Link[29] and push-up[27] exercises.

During a previous study, we found that using the Cuff Link in a push-up position with the straight-arm handles elicited 81.4% activation level of the serratus anterior compared with the MVIC.[29] Although we found similar activation levels with the bent-arm handles (74.56%) during the current study, participants in the previous study performed 5 continuous revolutions on the Cuff Link, and the middle 3 were averaged. The MVIC procedure was performed against an immovable weight rather than against manual resistance, but muscle activation was found to be representative of maximal activation. The MVIC procedures, continuous revolutions, and the use of the straight-arm handles may account for the slightly greater serratus anterior activation level in the previous study.

Moseley et al[25] determined that a push-up performed with the hands apart elicited a substantial amount of serratus anterior activity (69.0 ± 31.0%). However, the authors were vague in their description of the push-up protocol in terms of the distance between the participant's

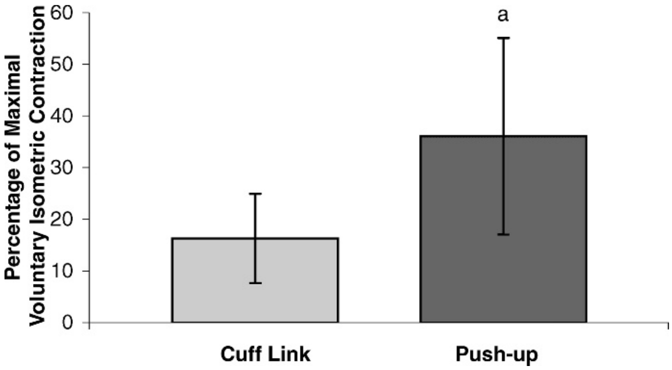

Figure 4. Electromyography results for the lower trapezius as a percentage of the maximal voluntary isometric contraction.
[a] Indicates $P \leq .001$.

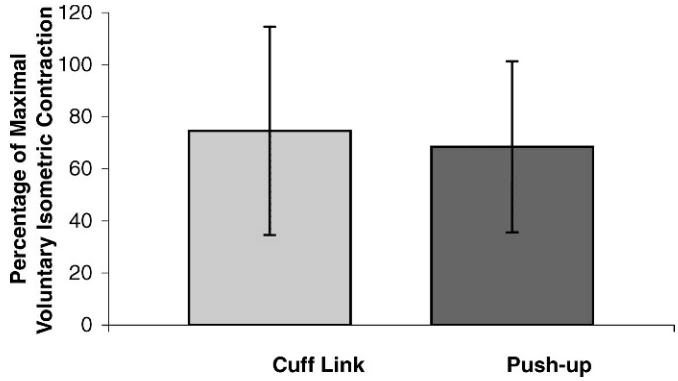

Figure 5. Electromyography results for the serratus anterior as a percentage of the maximal voluntary isometric contraction. The difference between the 2 conditions was not significant ($P = .159$).

hands and what defined "hands apart." Additionally, the authors used the peak second of a manual muscle test to normalize the EMG data during the testing of the exercise conditions. Nevertheless, their EMG findings for the serratus anterior were similar to our findings for the standard push-up.

Decker et al[28] investigated muscle activity of the serratus anterior during 8 shoulder exercises, including the push-up with a plus. Not including the plus phase, they found that the eccentric and concentric phases of a push-up elicited the second highest peak EMG amplitude (70.0 ± 29.2% and 100.0 ± 37.5%, respectively). Only the dynamic hug, which is a newly designed exercise, had a greater muscle activation level. Compared with our push-up results, these findings are slightly higher, but Decker et al[28] used a different MVIC procedure with resistance to chains rather than manual resistance. The use of peak EMG amplitude and the MVIC procedures may account for the greater EMG levels.

Ludewig et al[27] analyzed 4 progressions of a push-up with a plus with a velocity that was similar to the velocity that we used. Excluding their findings for the plus phase, they found that, in healthy participants, the standard push-up elicited the highest serratus anterior muscle activation during the concentric phase (more than 80% MVIC) and the lowest serratus anterior muscle activation during the eccentric phase (less than 50% MVIC). These serratus anterior results are similar to the results of our study (68.45%) in which the concentric and eccentric phases of the push-up were not separated.

Limitations

Our investigation had limitations. Studying the serratus anterior with surface electrodes provides accurate representation of the muscle's activation where the muscle is superficial at the middle and lower portions but not at the deeper, upper portion of the muscle. Additionally, we chose participants without shoulder disorders for this study because we intended to make conclusions based on muscle function during these exercises in normally functioning shoulders. However, results of muscle function in injured shoulders may vary from our results, and conclusions regarding shoulder disorders should be made with caution. Finally, we used an MVIC technique to normalize nonisometric activities. Differences in muscle length and force production may account for some increased variability resulting from different muscle contractions during the normalization and testing procedures.

CONCLUSIONS

Muscle activation levels of the middle trapezius and lower trapezius were larger during the push-up than during use of the Cuff Link. Although a slightly higher trend in EMG activation of the serratus anterior was noted during use of the Cuff Link, the serratus anterior activation levels of the 2 exercises were similar. When considering which of these 2 closed kinetic chain exercises to incorporate into an upper extremity rehabilitation protocol, the clinician should determine if higher levels of muscle activation are desired in all 3 muscles. When higher activation levels of all 3 muscles are needed, the standard push-up is the more appropriate exercise. If serratus anterior activation is the goal and the patient lacks sufficient upper body strength to perform a standard push-up, the Cuff Link is an appropriate alternative.

The ability of rehabilitative exercises to produce therapeutic levels of muscle contraction is clinically relevant. Future research is warranted to assess the capabilities of the Cuff Link and push-up to increase strength of the scapular muscles. Additionally, future authors should focus on analyzing muscle activation using the Cuff Link with other handle placements and on studying the Cuff Link in a plus position with participants in full scapular protraction, as has been done for push-up with a plus. Finally, efforts should be made to analyze the effects of the Cuff Link on participants with shoulder disorders, such as impingement syndrome, to assess the relationship between the serratus anterior and the trapezius in these patients. Through continued research, clinicians and researchers alike can gain a better understanding of the Cuff Link, the push-up, and other closed kinetic chain exercises for the upper extremity.

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W. Steven Tucker, MS, ATC, and Brian M. Campbell, PhD, contributed to conception and design; acquisition and analysis and interpretation of the data; and drafting, critical revision, and final approval of the article; Erik E. Swartz, PhD, ATC, contributed to analysis and interpretation of the data and drafting, critical revision, and final approval of the article. Charles W. Armstrong, PhD, contributed to conception and design; analysis and interpretation of the data; and critical revision and final approval of the article.

Address correspondence to W. Steven Tucker, MS, ATC, University of Central Arkansas, 201 Donaghey Avenue, Prince Center–113C, Conway, AR 72035. Address e-mail to stucker@uca.edu.