ABSTRACT

Background. Muscle strength and endurance of the shoulder rotators is important for overhead throwing performance and dynamic glenohumeral stability. Baseball pitching is distinguished as an intermittent activity with explosive, high intensity muscle contractions separated by periods of rest. Rotator cuff muscle performance could acutely decrease due to fatigue associated with bouts of throwing.

Objective. This study examined the effects of repeated overhead throwing upon isokinetic muscle performance of the shoulder rotators.

Methods. Repeated-measures analyses of variance were used to compare peak torque, total work, and work-fatigue by muscle group, time, and contraction type. Ten collegiate baseball pitchers underwent isokinetic testing of the internal (IR) and external shoulder (ER) rotators one week before and immediately after a throwing protocol of 60 maximal-effort pitches arranged into four innings of 15 pitches per inning. Isokinetic testing consisted of 12 concentric and eccentric repetitions at 300 deg/sec for internal and external rotation of the throwing extremity.

Results. The main effect of time and the interaction of muscle group and contraction type were significant for work-fatigue. Post-hoc analysis revealed that subjects had significantly greater eccentric IR work-fatigue (13.3 + 1%) compared to the pre-test (7.3 + 2%).

Discussion and Conclusion. Throwing-related fatigue affected both muscle groups, especially the IR, which has implications for dynamic glenohumeral stability. Rehabilitation and conditioning programs for competitive baseball pitchers should emphasize eccentric muscle endurance training of the shoulder rotators.

Key Terms: shoulder, baseball pitching, rotator cuff

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INTRODUCTION
Overhead throwing performance requires an intricate balance between the static and dynamic structures of the shoulder in order to maintain functional stability. Such integration requires muscular strength and endurance, flexibility, and neuromuscular control. If any one of these factors is compromised, functional instability results, performance diminishes, and shoulder injuries are more likely to occur.

Previous studies have investigated the influence of extended pitching primarily on kinetic and kinematic parameters of the pitching motion. Limited information exists on the effects of throwing on shoulder muscle strength and fatigue. Mullaney et al. examined the isometric muscle strength of various shoulder muscle groups after pitching multiple innings and indicated that upper extremity isometric muscle fatigue occurs in some shoulder and scapular muscles but not in the supraspinatus and external rotators. Since the supraspinatus and external rotators predominantly function dynamically during throwing, isometric assessment may not have been the appropriate testing-mode for evaluating supraspinatus and external rotation muscle function following a pitching performance.

Results from a study by Nocera et al. assessing shoulder strength of the external and internal rotators following throwing showed no significant decline when measured as a one repetition maximum (1RM) or as isokinetic peak torque. In addition, Mullaney and McHugh assessed isokinetic strength and reported that the shoulder rotators fatigue similarly during concentric and eccentric muscle actions. Despite these recent findings, no published information exists on the occurrence of shoulder rotator fatigue that is based on isokinetic work and described as a work-fatigue index. No documentation exists of muscle-specific fatigue within the shoulder internal and external rotators before or after repetitive overhead throwing. The hypothesis to be tested is that shoulder internal and external rotation musculature could experience work-fatigue as a result of throwing which might have implications for controlling dynamic glenohumeral stability; especially if muscle-specific fatigue exists. Therefore, the purpose of this study was to determine the effects of repeated overhead throwing on shoulder internal and external rotator isokinetic muscle fatigue following a pitching performance.

METHODS
Subjects
Ten male collegiate baseball pitchers (20.3 + 0.5 yr; 1.85 + 0.2 m; 88.1 + 2.8 kg) without injury to either shoulder volunteered to participate. Nine pitchers were right-hand dominant and one was left-hand dominant. Subjects averaged 10.1 + 0.9 years of pitching experience, dating back to youth league baseball. The Institutional Review Board of the University of South Alabama approved the study and all subjects gave informed consent to participate.

Instrumentation
Isokinetic testing of the shoulder rotator muscles was conducted using a Biodex System 3 (Biodex Corporation, Shirley, NY). Subjects were seated during the test with appropriate stabilization provided by a lap belt, criss-crossed chest straps, and footrest in accordance with the Biodex Isokinetic Dynamometer manual. The chair of the Biodex and the dynamometer attachment were individually adjusted to each subject to ensure proper fit and alignment and these settings were recorded from the numerical scale on the machine and attachment. A Velcro® strap was used to secure the forearm in the dynamometer attachment cradle. The upper extremity was positioned in shoulder abduction at 90º of elbow flexion and shoulder rotation was performed from 90º external rotation to 60º internal rotation, for a total range of motion of 150º. Gravity compensation was performed prior to each test.

Procedures
Subjects participated in two isokinetic tests (pre and post-throwing) and one pitching session. All testing was preceded by an orientation session in which the isokinetic testing and throwing protocols were explained and each subject performed isokinetic exercise to become familiar with the testing protocol.

Seven days before performing the throwing protocol, subjects participated in isokinetic testing of the shoulder internal rotators (IR) and external rotators (ER) by performing 12 concentric and eccentric contractions at 300 deg/sec. Subjects were given detailed verbal instruction of procedures and performed five warm-up
repetitions prior to each test. For the IR and ER muscle groups, concentric contractions were tested initially, a 3-minute rest provided, and then the eccentric testing was performed. Each muscle group worked for approximately six seconds during the 12 repetition set. With 180 seconds to recover, this provided a work-rest ratio of 1:30. Since each muscle group only worked for approximately six seconds, intramuscular ATP should have been adequately regenerated. Stone and Connelly showed that complete ATP-phosphocreatine resynthesis occurs with a work:rest ratio of at least 1:12. Subjects were verbally encouraged to maximally move the extremity “as hard and as fast as possible” during concentric testing and to "resist or fight" the movement of the dynamometer attachment with eccentric testing. Subjects were not allowed visual feedback during testing.

Subjects returned one week after performing the pre-throwing isokinetic test and participated in the throwing session. All subjects stretched and warmed-up prior to pitching. Subjects threw from a standard pitching mound located in an outdoor bullpen, which was elevated 0.254 meters above the level of home plate. Throws were made to a catcher located behind home plate at a distance of 18.4 meters from the pitching mound and threw a baseball that weighed 0.14 kilograms. Maximum throwing speed was measured using a Jugs Radar Model 620-c Gun (Decatur Electronics; Decatur, IL) and calibrated with a tuning fork prior to all throwing sessions.

Each subject threw 60 maximal-effort pitches (all fastballs) arranged into four innings of 15 pitches per inning. Five pitches were thrown as a warm-up at the beginning of each inning at a self-selected intensity (straight fastballs only). The pitch rate was standardized by throwing every 15 seconds, which yielded a total of five minutes of throwing per half inning. Following the completion of 20 pitches (5 warm-up and 15 maximal throws), the subject rested in a seated position for five minutes before throwing another inning. Thus, the throwing protocol consisted of 20 minutes of pitching and 20 minutes of seated rest. One author monitored the pitches thrown, rest between innings, and recorded pitch velocities.

Subjects performed the second isokinetic test immediately following the completion of the throwing session. The procedures used were identical to those of the pre-throwing test.

Data Analysis
The work-fatigue index (means + SEM) was recorded for concentric and eccentric IR and ER. Work-fatigue is the difference between the first one-third (first four repetitions of the 12) and last one-third (last four repetitions) of the work (Nm/kg) performed in a given set, which is then divided by the work in the first one-third of the set and multiplied by 100. This index measures the amount of fatigue from the beginning to the end of an endurance test bout, with a larger work-fatigue index value indicating greater fatigue.

Reliability of the work-fatigue index was previously determined using ten additional healthy male subjects. Each subject performed 12 repetitions for concentric and eccentric ER and IR at 300 deg/sec, which was repeated one week later. Intra-class coefficients (ICC) ranged from 0.66 to 0.81. The ICC data were as follows: concentric ER = 0.69 (95% CI = 0.60-0.74); concentric IR = 0.81 (95% CI = 0.73-0.89); eccentric ER = 0.66 (95% CI = 0.59-0.72); and eccentric IR = 0.79 (95% CI = 0.73-0.84). These ICCs are considered to be “moderate” in strength, as ICC values of 0.75 or greater generally indicate high reliability.

Concentric and eccentric peak torques and total work were normalized to body mass (Nm/kg). These data were analyzed for descriptive purposes and to document shoulder rotator strength across the pre- and post-test trials.

Data were analyzed with repeated measures analysis of variance (ANOVA) using within-subjects factors of muscle group (ER and IR), muscle action (concentric and eccentric), and time (pre-throwing and post-throwing). Post hoc analyses consisted of paired t-tests corrected for alpha inflation by the Bonferonni procedure. Additionally, to provide an indication of whether work-fatigue was indeed a meaningful measure of fatigue, a one-sample t-test was used to compare the work-fatigue index to a baseline value of zero that represented zero percent fatigue.

All statistical analyses set the alpha level at 0.05. Power was set to be 80% Apriori. Using ten subjects it was determined that a 12% difference in percent fatigue could be detected from pre-test to post-test assuming that the within subject variability was similar to values previously reported.
RESULTS
The average pitched ball velocity was $36.7 \pm 1.2$ m/s (82.1 ± 2.7 mph). The average ball velocity in the first inning was $36.87 \pm 0.6$ m/s (82.5 ± 1.3 mph), which was not statistically different ($p = 0.12$) from the ball velocity in the final inning (36.43 ± 0.4 m/s or 81.5 ± 0.9 mph). The mean time from the last ball thrown to commencement of the isokinetic post-test was 12.0 ± 0.8 minutes.

Isokinetic Work-Fatigue Index
The main effect of time was significant ($p < 0.01$) for work-fatigue across muscle groups and muscle actions, with greater work-fatigue observed in the post-test (15.5 ± 1%) when compared to the pre-test (7.6 ± 2%). Post-hoc analysis ($p < 0.01$) showed greater eccentric IR work-fatigue following the throwing bout (13.3 ± 1%) when compared to the pretest (7.3 ± 2%). No significant main effects for work-fatigue were found for muscle group ($p = 0.07$) or muscle action ($p = 0.14$) (Table 1).

The work-fatigue interaction for muscle group and muscle action was significant ($p < 0.02$). Post-hoc tests ($p < 0.01$) indicated greater eccentric IR work-fatigue (13.8 ± 2%) compared to the IR (7.3 ± 2%) for the pretest only.

For the pretest trial, only the eccentric ER work-fatigue index was significantly greater ($p < 0.001$) from the zero-fatigue baseline condition. Whereas, for the post-test trial, both the concentric and eccentric ER and IR work-fatigue values were found to be significantly different ($p < 0.05$) from the zero-fatigue baseline condition (Table 1). This finding shows that work-fatigue values are indicative of fatigue occurring.

Total Work and Peak Torque
Total work and peak torque values normalized to body weight are presented in Tables 1 and 2. Significant peak torque main effects ($p < 0.05$) for muscle group and contraction mode existed, but not for time ($p > 0.05$). Comparisons showed that IR eccentric and concentric total work and peak torque were greater than ER eccentric and concentric values, respectively.

DISCUSSION
A paucity of research exists examining the impact of muscle fatigue on upper extremity muscle function in the throwing athlete. Increasing our understanding of these effects may be imperative in preventing injury.5,10,20 The practical significance of this study was that shoulder rotator work-fatigue was observed in both muscle groups and in both muscle actions after a bout of repetitive throwing. Specifically, a significant difference pre to post-test for work-fatigue was found. Post-hoc analysis revealed greater eccentric IR work-fatigue (13.3 ± 1%) compared to the pre-test (7.3 ± 2%).

The importance of these findings appears clinically relevant to the biomechanics of pitching. The rotator cuff muscles are active throughout the entire throwing motion, with activity levels peaking during the cocking phase, as the infraspinatus and teres minor provide external rotation and the subscapularis and supraspinatus assist in providing stability to the glenohumeral joint.21 The findings support the hypothesis that repetitive eccentric IR activity during the cocking phase of throwing diminished the thrower’s capacity to maintain work output over the 12 repetitions of the isokinetic post-test. Increased fatigue could lead to a lack of coordination and control by the

<table>
<thead>
<tr>
<th>Muscle Group</th>
<th>Total Work</th>
<th>Work Fatigue</th>
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<tbody>
<tr>
<td>ER**</td>
<td>Concentric</td>
<td>Concentric</td>
</tr>
<tr>
<td></td>
<td>pre-test</td>
<td>6.74 ± 0.44</td>
</tr>
<tr>
<td></td>
<td>post-test</td>
<td>6.81 ± 0.44</td>
</tr>
<tr>
<td>IR**</td>
<td>Concentric</td>
<td>Concentric</td>
</tr>
<tr>
<td></td>
<td>pre-test</td>
<td>10.23 ± 0.97</td>
</tr>
<tr>
<td></td>
<td>post-test</td>
<td>10.59 ± 0.68</td>
</tr>
</tbody>
</table>

Table 1. Normalized total work (Ng/kg) and work-fatigue (Means ± SEM)

IR: Internal Rotators
ER: External Rotators
* Eccentric total work (TW) > concentric TW ($p<0.05$)
† IR TW > ER TW ($p<0.05$)
†‡ Post-test IR work-fatigue > pretest IR work-fatigue ($p<0.05$)
§ Eccentric ER work-fatigue > eccentric IR work-fatigue at pre-test ($p<0.01$)
¶ Work-fatigue values were significantly different from 0.0 ($p<0.05$)
is difficult when metabolic recovery is likely to occur. In this study, the elapsed time of approximately 12 minutes from the completion of the throwing bout to the isokinetic post-test could have been sufficient to allow metabolic recovery and, thus, no differences in peak torque would be expected.

Table 2. Normalized peak torque (Nm/kg)
Means ± SEM

<table>
<thead>
<tr>
<th></th>
<th>Concentric</th>
<th>Eccentric</th>
</tr>
</thead>
<tbody>
<tr>
<td>ER</td>
<td>pre-test</td>
<td>0.38 ± 0.02</td>
</tr>
<tr>
<td></td>
<td>post-test</td>
<td>0.39 ± 0.02</td>
</tr>
<tr>
<td>IR</td>
<td>pre-test</td>
<td>0.60 ± 0.04†</td>
</tr>
<tr>
<td></td>
<td>post-test</td>
<td>0.63 ± 0.03†</td>
</tr>
</tbody>
</table>

IR: Internal Rotators
ER: External Rotators
* Eccentric > concentric (p<0.05)
† IR > ER (p<0.05)
Post-hoc analysis showed greater post-test work fatigue (13.3%) when compared to the pre-test (7.3%) for only the shoulder IR muscles. This finding is similar to those of Mullaney et al.\textsuperscript{10} who reported that repetitive overhead throwing caused an 18% decrease in post-game IR isometric muscle strength. In addition, Mullaney et al.\textsuperscript{10} observed no significant decrease in the isometric muscle force of the ER following throwing. The findings in this study and those previously reported by Mullaney et al.\textsuperscript{10} demonstrate the high performance demands placed on the IR during repetitive overhead throwing. The absence of measurable isometric fatigue assessed by isometric testing could be explained by the dynamic nature by which the ER muscles function during throwing.\textsuperscript{3} This finding further illustrates the importance of muscle testing specificity and the significance of assessing a performance-related activity such as throwing.

**Clinical Implications**

Shoulder rotator cuff muscle strength and endurance is important to act against potentially injurious forces produced during the throwing motion.\textsuperscript{9,28} Distraction forces commonly reach or surpass equivalency to body mass and the failure to counteract these forces is often cited as a potential injury mechanism for repetitive microtrauma.\textsuperscript{3,8,28} Repetitive microtrauma related to multiple bouts of overhead throwing is thought to contribute to injury of the rotator cuff musculature, which is one of the most common injuries in baseball pitchers.\textsuperscript{6,29,31} Andrews and Wilk\textsuperscript{8} proposed that the repetitive microtrauma associated with throwing leads to tissue fatigue, inflammation, decreased muscle performance with resulting instability, and ultimately tissue damage.

Insidious rotator cuff injury could be associated with impaired dynamic stability related to muscle fatigue.\textsuperscript{3} The finding that the eccentric fatigue occurred in both muscle groups after throwing is an important consideration about dynamic stability during prolonged bouts of overhead throwing.\textsuperscript{8} For pitchers lacking ER eccentric fatigue resistance, dynamic stability may be compromised during arm deceleration in latter innings compared to early innings. This reduction in eccentric work coupled with a fatigue-induced decline of joint position sense\textsuperscript{2,32} could allow superior migration of the humeral head on the face of the glenoid fossa that is associated with impingement and other glenohumeral injuries.\textsuperscript{9,33} It is well documented that the IR muscles are stronger than ER,\textsuperscript{10,15,23,34-38} but we found that throwing induced similar percentages of fatigue in both muscle groups in both concentric and eccentric muscle actions.

**CONCLUSION**

The results of this study demonstrated greater IR and ER work-fatigue after a pitching performance with the IR eccentric work-fatigue showing the greatest fatigue. These findings have implications for pre-season conditioning and post-injury rehabilitation of overhead throwing athletes and underscore the importance of eccentric endurance training exercise for the rotator cuff musculature. Future studies are necessary to validate these findings and to further determine the clinical usefulness of the work-fatigue index.

**REFERENCES**


ABSTRACT

**Background.** Knee pain can cause a deconditioned knee. Deconditioned is defined as causing one to lose physical fitness. Therefore, a deconditioned knee is defined as a painful syndrome caused by anatomical or functional abnormalities that result in a knee flexion contracture (functional loss of knee extension), decreased strength, and decreased function. To date, no published studies exist examining treatment for a deconditioned knee.

**Objective.** To determine the effectiveness of a rehabilitation program focused on increasing range of motion for patients with a deconditioned knee.

**Methods.** Fifty patients (mean age 53.2 years) enrolled in the study. Objective evaluation included radiographs, knee range of motion, and isokinetic strength testing. The International Knee Documentation Committee (IKDC) subjective questionnaire was used to measure symptoms and function. Patients were given a rehabilitation program to increase knee extension (including hyperextension) and flexion equal to the normal knee, after which patients were instructed in leg strengthening exercises.

**Results.** Knee extension significantly improved from a mean deficit of 10° to 3° and knee flexion significantly improved from a mean deficit of 19° to 9°. The IKDC survey scores significantly improved from a mean of 34.5 points to 70.5 points 1 year after beginning treatment. The IKDC subjective pain frequency and severity scores were significantly improved.

**Conclusions.** A rehabilitation program that improves knee range of motion can relieve pain and improve function for patients with a deconditioned knee.

**Key Words.** knee pain, flexion contracture, range of motion

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K. Donald Shelbourne, MD is a consultant to Kneebourne Therapeutics, Inc.

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INTRODUCTION
Knee pain is a common complaint and reason for people to seek medical care by a primary care physician or an orthopaedic surgeon. Each year over 1 million emergency room visits and 1.9 million visits to primary care physicians are for complaints of knee pain. Knee pain can be caused by an acute knee injury, or many times, the pain is chronic and can progressively get worse with time. Approximately 30% of adults 65 years of age and older report knee pain or stiffness in the past 30 days. Sixty percent of adults 65 years and older and 37% of young adults age 20 to 44 report pain lasting 1 year or more, with the knee joint being the most common area of pain cited. People who have persistent knee pain often favor the painful knee. As a result, he or she may lose knee range of motion, develop a knee flexion contracture, and lose strength, which alters the normal function of the knee. Deconditioned means causing one to lose physical fitness. Therefore, a deconditioned knee is described as a painful syndrome caused by anatomical or functional abnormalities that result in a knee flexion contracture (functional loss of knee extension), decreased strength, and decreased function.

A deconditioned knee may occur from osteoarthritis or a knee that has not been completely rehabilitated after a surgery or injury. This condition may also result from extreme overuse, failed previous knee surgery, or from favoring one knee over the other for an extended period of time. Patients who develop a knee flexion contracture experience rehabilitation difficulty because a knee with a flexion contracture is difficult to strengthen. Patients are often treated with medication, braces, foot orthotics, or knee surgery. However, these treatment options do not specifically address the loss of knee range of motion.

Studies of patients with knee pain and osteoarthritis have shown that rehabilitation programs that include manual therapy, strengthening exercises, hydrotherapy, or general exercise can reduce pain and improve function. Other similar studies have found no benefit from exercise programs or that exercises are most helpful when conducted in a supervised setting. According to the Philadelphia Panel systematic review on rehabilitation interventions for knee pain, transcutaneous electrical nerve stimulation (TENS) and therapeutic exercise were beneficial for knee osteoarthritis. However, a void remains in the literature demonstrating the effectiveness of specific therapeutic exercises correlated with a valid and reliable outcome measurement tool. In addition, no published literature exists that describes the effectiveness of increasing range of motion in the treatment of a deconditioned knee.

Range of motion is a critical factor in determining the clinical outcome following total knee arthroplasty. It is also an important factor following anterior cruciate ligament reconstruction. Research has shown that obtaining full knee hyperextension equal to the opposite normal knee is one of the most important factors in contributing to a successful outcome after anterior cruciate ligament reconstruction. Even 3° to 5° of extension loss resulted in a poorer outcome.

In many text books, knee range of motion is described as 0° of extension and 135° of flexion. According to a study by De Carlo and Sell, however, 96% of the population has some degree of hyperextension. They found normal knee extension to be a mean of 5° of hyperextension in males and 6° of hyperextension in females.

Given that knee extension is an important factor in the success of surgical treatment, this study was performed to determine the relevance of full knee extension in the treatment of chronic knee conditions described as a deconditioned knee. No studies exist that have examined whether an improvement of knee range of motion to normal (equal to the opposite normal knee) can reduce subjective complaints of patients with chronic knee pain. Therefore, the purpose of this study was to determine the effectiveness of a rehabilitation program that focused on improving knee range of motion to treat patients with a deconditioned knee. The hypothesis to be tested was that patients who underwent rehabilitation to improve knee range of motion would have a statistically significant improvement in subjective knee pain scores.

METHODS
A power analysis was performed before the study began. An improvement of 10 points on the subjective knee questionnaire would be considered a clinical improvement. A sample size of 41 patients was required for α = 0.05 and power = 0.80.
Patients who complained of knee pain and had a lack of knee range of motion were prospectively asked to enroll in the study. To be included in the study, the patient had to have a knee flexion contracture of at least 5º, could not be taking any narcotic pain medication, and had to have an intact anterior cruciate ligament. Exclusion criteria included patients with bilateral knee pain or who had an injury or condition that would obviously explain pain or lack of knee range of motion (i.e. meniscus tear) and required surgical intervention. Patients signed a voluntary consent approved by the Institutional Review Board at Methodist Hospital in Indianapolis.

Radiographs were obtained at the initial visit and the posterior 45º flexed weightbearing view was used to evaluate for osteoarthritis. Patients attended physical therapy and were given a rehabilitation program that included exercises to restore full knee extension equal to the opposite normal knee first, followed by exercises to restore normal knee flexion. Light strengthening exercises were prescribed as needed when knee range of motion was restored, and the exercises included the stationary bike, single leg press, and single leg extension.

The IKDC (International Knee Documentation Committee) subjective survey was used to evaluate pain, activity, and knee function. The IKDC is a reliable, responsive, and validated instrument used to assess symptoms, function, and sports activity in patients with a variety of knee disorders. In addition, normative data is available to assist in the interpretation of the subjective results. Patients were asked to complete the questionnaire independently in a private treatment room at the initial visit and at 1 and 3 months after initial treatment. The same questionnaire was sent in the mail to patients at 6 and 12 months after the initial visit.

Range of motion measurements were taken using a goniometer as described by Norkin and White. Range of motion measurements were recorded as A-B-C, with A being the degrees of hyperextension, B indicating lack of extension from zero, and C documenting the degrees of flexion. Measurements were taken by the treating physical therapist. Intra-tester and inter-tester reliability measurements of the treating therapists were high (kappa > 0.8) for both flexion and extension. Knee range of motion was recorded at the initial visit and at 1 and 3 months after the initial visit. The IKDC objective form grades range of motion as normal, nearly normal, abnormal, or severely abnormal. Range of motion was graded according to IKDC criteria (Table 1).

Quadriceps muscle strength was evaluated by the treating physical therapist with isokinetic strength testing performed at 180º/sec at the 1 month and 3 month visit. The strength test was not performed at the initial visit because most patients’ knees were too painful for them to tolerate the evaluation.

<table>
<thead>
<tr>
<th>IKDC ratinga</th>
<th>Extension difference in degrees</th>
<th>Flexion difference in degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>&lt;2</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Nearly Normal</td>
<td>3-5</td>
<td>6-15</td>
</tr>
<tr>
<td>Abnormal</td>
<td>6-10</td>
<td>16-25</td>
</tr>
<tr>
<td>Severely Abnormal</td>
<td>&gt;10</td>
<td>&gt;25</td>
</tr>
</tbody>
</table>

*The difference in range of motion is compared with the opposite normal knee to include hyperextension.

Patients who required surgical intervention for symptoms were considered a failure of rehabilitation treatment.

**Rehabilitation Program**

Patients were instructed and issued a home exercise program that focused on improving knee extension first. Patients were instructed in prone hang exercises, heel prop exercises, and towel extension stretches (Figure 1) to increase knee extension equal to the opposite normal knee. The

**Figure 1. Towel stretch exercises. The patient holds on to the ends of a towel that is wrapped around the ball of the foot. While using one hand to hold the top part of the leg down on the table, the other hand pulls the ends of the towel so that the knee is hyperextended and the heel of the foot comes up off the table.**
patients were instructed to perform 10 repetitions of each exercise 3x/day. If patients were unable to achieve normal knee extension through the previous exercises, a hyperextension device (Elite Seat, Kneebourne Therapeutic, Noblesville, IN) (Figure 2) was utilized in addition to the other extension exercises. Patients were instructed to use the extension device for 10 minutes 3x/day.

In addition to exercises, patients were educated in daily habits to be performed throughout the day to help maintain knee extension gained by the exercises. These extension habits included performing heel prop exercises while sitting or standing on the involved extremity with the knee locked out forcing the knee into full hyperextension via an active quadriceps contraction (Figure 3). Improving knee extension remained the focus of the treatment until full hyperextension equal to the opposite knee was achieved. Patients were also encouraged to ice their knee for swelling and soreness as needed.

As knee extension improved towards normal, the exercise program was progressed to include flexion exercises if a deficit was present. The knee flexion exercises included heel slides while sitting and wall slides while lying supine; again, all exercises were performed at 10 repetitions 3x/day.

Upon near full range of motion, patients were instructed to begin a low impact aerobic exercise such as the bike, elliptical, or stair-stepping machine. They were also instructed in light strengthening exercises including single leg press, leg extensions, quarter squats, and step down exercises. Patients were continually encouraged to maintain full range of motion while advancing their exercise program of low impact activity and leg strengthening exercises.

Data Analysis

Descriptive statistics were used to determine the mean knee range of motion at each visit and the mean IKDC subjective scores at each observation. Data analysis comparing pre-treatment and post-treatment subjective scores was performed on patients who completed the study. Two-tailed t-test was used to determine whether a statistically significant difference existed between initial and final values for parametric data of IKDC total scores and isokinetic quadriceps muscle strength scores. Wilcoxon signed-rank test was used to determine whether there was a statistically significant difference between initial and final values for nonparametric data of knee extension, knee flexion, and IKDC pain frequency and severity scores. Repeated measures analysis of variance was used to determine if the IKDC total subjective scores improved through time after the initial visit. For all statistical analysis, the 0.5 level of probability was used. Due to the fact that six t tests were performed on this part of the study, a Boneferroni adjustment was performed, (0.05/6) thereby, setting the alpha level at p<0.008.

The IKDC subjective score of patients in this study was compared with normative IKDC data obtained by the IKDC committee. Anderson et al compiled normative data for 5,246 knees of men and women in four age groups (18-24 years, 25 to 34 years, 35 to 50 years, 51 to 65 years) and means for the groups were established. The investigators offered a formula for converting raw IKDC subjective scores to a standardized score that would give the standard deviation units above or
below the population average, which was then applied to the present study group. A one sample t-test was performed to determine if the standardized IKDC score was significantly different than zero for each sex and age group. Again, the level of probability was set at p<0.05 and following a Bonneferoni correction due to four t tests (0.05/4), the alpha level was adjusted to p<0.013.

RESULTS
Fifty patients enrolled into the study; 42 patients completed the study and 8 patients were considered a failure of treatment because they underwent a surgical procedure by other physicians for their symptoms. The mean age of patients (25 men; 25 women) at the time of enrollment into the study was 53.2 ± 9.9 years (range 25.0 to 72.4) and no significant difference in age existed between men and women. The underlying pathology in the knee was osteoarthritis in 41 patients, previous arthroscopy without rehabilitation in seven patients, and disuse osteoporosis in two patients.

A statistically significant improvement was found in knee extension, knee flexion, and quadriceps muscle strength from initial evaluation to final follow-up (Table 3). At the initial evaluation, the mean range of motion in the non-involved knee was from 4° of hyperextension to 135° of flexion, and 44 of 50 patients had some degree of hyperextension in their normal knee (range 1° to 15°). The mean deficit in knee range of motion compared with the opposite normal knee was 10° of extension and 19° of flexion. The mean deficit in knee range of motion at final follow-up was 3° of extension and 9° of flexion, which was a statistically significant improvement for both extension and flexion (p<0.008). Twenty patients achieved what is considered normal knee extension (within 2° of the uninvolved knee). Sixteen patients achieved knee extension that is considered nearly normal (within 5° of the uninvolved knee), and six patients had abnormal extension (lacking 6° to 10° of extension compared to the uninvolved knee). All patients had improvement in knee extension and all but four patients had improvement in knee flexion. The mean improvement in extension was 6° (range 1° to 11°) and the mean improvement in flexion being 10° (range 0°-40°; Table 3).

Eight patients were considered a failure of rehabilitation treatment because they had subsequently undergone surgical intervention for their symptoms. Three patients had a total knee arthroplasty, four patients had a knee arthroscopy, and one patient had a meniscal transplant. All eight patients, however, had improvement in knee extension (mean 5°, range 1° to 10°) and five of eight patients had improvement in flexion (mean 5°, range -5 to 15). Furthermore, the IKDC subjective scores improved from a mean of 30.8 ± 9.5 points to 45.7 ± 18.7 points, although this improvement is not statistically significant (p=0.0675).

Table 2. Grade and compartment of osteoarthritis at time of initial evaluation

<table>
<thead>
<tr>
<th>Compartments Involved</th>
<th>Grade of arthrosis (number of patients)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mild</td>
</tr>
<tr>
<td>Medial only</td>
<td>7</td>
</tr>
<tr>
<td>Lateral only</td>
<td>2</td>
</tr>
<tr>
<td>Patellofemoral only</td>
<td>0</td>
</tr>
<tr>
<td>Medial and lateral</td>
<td>0</td>
</tr>
<tr>
<td>Medial, lateral, and patellofemoral</td>
<td>0</td>
</tr>
<tr>
<td>Medial and patellofemoral</td>
<td>1</td>
</tr>
<tr>
<td>Lateral and patellofemoral</td>
<td>0</td>
</tr>
</tbody>
</table>

International Knee Documentation Committee survey scores significantly improved with treatment from a mean of 34.5 ± 14.0 points to 70.5 ± 20.6 points (p<0.008). Repeated measures analysis of variance showed that the mean IKDC subjective scores significantly improved (p<0.008) through time with the greatest increase in scores being from the initial evaluation to the one month evaluation (Figure 4).

The IKDC subjective survey evaluates both severity and frequency of pain on a scale of 0 to 10, with 0 being “no pain” and frequency as “never” and 10 being “worst pain imaginable” and “constant” frequency. The mean score of pain frequency significantly improved from 8.7 ± 3.3 points to 3.3 ± 2.8 points (p<0.008). Similarly, the mean score for pain severity significantly improved from 6.0 ± 2.0 points to 2.5 ± 2.3 points (p<0.008).
The final total IKDC subjective scores for the study group compared with normative data is shown in Table 4, which include the mean IKDC standardized score showing the standard deviation above or below the population average. The one sample t-test comparing the IKDC scores between the study group and normative data showed that no statistically significant difference existed for men or women in the different age groups (Table 4).

**DISCUSSION**

The results of this study show the effectiveness of a rehabilitation program that focused on increasing range of motion equal to the opposite normal knee to improve subjective symptoms in patients with deconditioned knees. The results demonstrate the effectiveness of non-operative rehabilitation in treating a deconditioned knee. This particular study shows that knee pain and function can significantly improve by increasing knee range of motion and, in particular, knee extension.

The underlying knee pathology causing pain in many of the patients in this study was osteoarthritis. Most of these patients had been told by other physicians that they needed a total knee arthroplasty or arthroscopic procedure to alleviate their pain. However, 84% of the patients in this study improved with non-operative treatment. These results demonstrate that physical therapy can improve

### Table 3. Results summary.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
<th>Range</th>
<th>p-value</th>
<th>t values</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Extension</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial deficit</td>
<td>10° ± 5°</td>
<td>5° - 34°</td>
<td>p&lt;0.008</td>
<td>8.8</td>
</tr>
<tr>
<td>Final deficit</td>
<td>3° ± 2°</td>
<td>0° - 10°</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Flexion</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial deficit</td>
<td>19° ± 14°</td>
<td>1° - 70°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final deficit</td>
<td>9° ± 11°</td>
<td>0° - 62°</td>
<td>p&lt;0.008</td>
<td>6.6</td>
</tr>
<tr>
<td><strong>IKDC subjective (points)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial evaluation</td>
<td>34.5 ± 14.0</td>
<td>8 – 85</td>
<td>p&lt;0.008</td>
<td>-11.2</td>
</tr>
<tr>
<td>Final evaluation</td>
<td>70.5 ± 20.0</td>
<td>20 – 100</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>IKDC pain frequency†</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial evaluation</td>
<td>8.7 ± 1.5</td>
<td>5 – 10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final evaluation</td>
<td>3.3 ± 2.8</td>
<td>0 – 9</td>
<td>p&lt;0.008</td>
<td>12.3</td>
</tr>
<tr>
<td><strong>IKDC pain severity†</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial evaluation</td>
<td>6.0 ± 2.0</td>
<td>1 – 10</td>
<td>p&lt;0.008</td>
<td>8.5</td>
</tr>
<tr>
<td>Final evaluation</td>
<td>2.5 ± 2.3</td>
<td>0 – 9</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Quadriceps muscle strength‡</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 month evaluation</td>
<td>73.8 ± 18.4</td>
<td>30 – 112</td>
<td>p&lt;0.008</td>
<td>-5.9</td>
</tr>
<tr>
<td>Final evaluation</td>
<td>86.9 ± 14.5</td>
<td>62 – 110</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* IKDC subjective questionnaire is scored from 0 to 100 points with 100 points indicating no pain, symptoms, or lack of function.
† IKDC pain frequency and severity are graded on a scale of 0 to 10, with 0 being “no pain” and frequency as “never” and 10 being “worst pain imaginable” and “constant” frequency.
‡ Quadriceps muscle strength was evaluated with isokinetic testing at 180°/sec.

**Figure 4:** The mean subjective scores improved through time with the greatest improvement obtained between the initial evaluation and one month follow-up.
knee pain and function with non-operative treatment, which is an important factor considering rising health care costs. Non-operative treatment can be more effective and cost efficient to the patient and insurance companies.

Forty-two of 50 patients completed the study and 38 of 42 patients had improvement in knee extension, knee flexion, and subjective outcome measures. Only eight of the 50 patients (16%) dropped out of the study to undergo a surgical procedure. These eight patients all had some degree of improvement in knee extension, which is an important factor in determining the success after surgery. So, although eight patients underwent surgery, the improvement in range of motion obtained pre-operatively may help minimize post-operative range of motion complications.

When comparing the mean IKDC score from the study group to the normative data, there was no statistical difference for patients of the same sex and age group. This fact indicates that the rehabilitation program was effective for returning patients back to a normal level of function for their age group.

The loss of knee extension is common after knee surgery, knee injury, or knee pain. While recovering, it is a person’s natural tendency to favor the involved extremity and stand with the involved knee bent, unless otherwise instructed to do so. Within a short period of time, even days, a person can develop a flexion contracture resulting in a loss of motion and subsequent loss of leg strength. Many times, the patient is unaware that a loss of knee extension has occurred because the deficit has come on gradually. A typical scenario is one where the patient has seen a physician for knee pain and has been told to reduce activities to accommodate the pain. While this habit can temporarily make the knee feel better, it does nothing to assist the patient with functioning normally with everyday activities.

A thorough and accurate knee evaluation is critical to recognizing knee asymmetry. During evaluation, a flexion contracture can often be observed when the patient is lying supine on the table. When the patient is unable to fully extend the knee, he or she must externally rotate the hip (Figure 5). Another way to observe the patient is during standing. Patients with a flexion contracture will typically stand with the involved knee bent and most of their weight is placed on the non-involved leg. These observation techniques alert the clinician to the possible presence of a flexion contracture. In addition to taking goniometric measurements, it is important to assess the passive end feel of knee extension (Figure 6). Examining the normal knee first will help identify what is normal for that individual.

<table>
<thead>
<tr>
<th>Sex/Age Group (n)*</th>
<th>Study Group (mean ± SD)</th>
<th>Normative data (mean ± SD)</th>
<th>Mean difference from 0†</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female 35 – 50 years (5)</td>
<td>75.2 ± 22.3</td>
<td>79.9 ± 22.6</td>
<td>-0.208</td>
<td>0.6614</td>
</tr>
<tr>
<td>Female 51 – 65 years (15)</td>
<td>62.0 ± 21.8</td>
<td>70.9 ± 26.0</td>
<td>-0.310</td>
<td>0.1740</td>
</tr>
<tr>
<td>Male 35 – 50 years (9)</td>
<td>77.9 ± 23.4</td>
<td>84.9 ± 19.3</td>
<td>-0.364</td>
<td>0.3949</td>
</tr>
<tr>
<td>Male 51 – 65 years (9)</td>
<td>77.3 ± 13.8</td>
<td>77.4 ± 23.3</td>
<td>-0.004</td>
<td>0.9826</td>
</tr>
</tbody>
</table>

*Four patients were older than 65 and could not be included in the analysis
†Formula was used to convert each patient’s IKDC subjective score to a standardized score showing the standard deviation difference above or below the population average.

$$z = \frac{\text{Patient’s IKDC subjective score} - \text{mean score for age/gender group}}{\text{Standard deviation for age/gender group}}$$

Table 4. Final IKDC total scores compared with normative data.
Regaining full knee hyperextension can provide long lasting relief. The mean IKDC subjective score improved significantly between the initial and the 1 month follow-up evaluation, and patients continued to have subjective improvement through the latest evaluation at 1 year after receiving treatment. While rehabilitation sessions can be successful for improving knee extension, the patient must change daily habits to be able to maintain the gains achieved. Educating the patient regarding normal gait and how to stand and properly use the involved extremity is an important factor in maintaining the improvements gained.

CONCLUSION
A rehabilitation program that focuses on increasing range of motion, in particular knee extension, can relieve symptoms and improve function for patients diagnosed with a deconditioned knee. Physical therapy and non-operative treatment should be considered as a primary treatment objective in the treatment of a deconditioned knee regardless of the underlying pathology. As shown in this study, most patients with a deconditioned knee can be treated effectively through non-operative management.

REFERENCES:


ABSTRACT

Background. Upper extremity weight-bearing exercises are routinely used in physical therapy for patients with shoulder pathology. However, little evidence exists regarding the demand on the shoulder musculature.

Objective. To examine changes in shoulder muscle activity and center of pressure during upper extremity weight-bearing exercises of increasing difficulty.

Methods. Electromyographic (EMG) and kinetic data were recorded from both shoulders of 15 healthy subjects (10 male and 5 female). Participants were tested in a modified tripod position under three conditions of increasing difficulty: (1) hand directly on the force plate, (2) on a green Stability Trainer™ and (3) on a blue Stability Trainer™. Ground reaction forces were recorded for each trial. Surface EMG was recorded from the serratus anterior, pectoralis major, upper trapezius, lower trapezius, infraspinatus, anterior deltoid, posterior deltoid, and the lateral head of the triceps muscles.

Results. Mean deviation from center of pressure significantly increased when using the Stability Trainer™ pads. The activities of the triceps, serratus anterior, and anterior deltoid muscles significantly increased as each trial progressed, irrespective of stability condition. Additionally, activity in the anterior deltoid, lower trapezius, and serratus anterior muscles significantly decreased with increasing difficulty, whereas activity in the triceps muscles significantly increased.

Discussion and Conclusion. Balancing on a foam pad made it more difficult to maintain the upper extremity in a stable position. However, this activity did not alter the proprioceptive stimulus enough to elicit an increase in shoulder muscle activation. While the results of this study support the use of different level Stability Trainers™ to facilitate neuromuscular re-education, a less compliant unstable surface may produce larger training effects.

Key Words: closed chain, shoulder, muscle activity.

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INTRODUCTION

During activities of daily living and sports, the upper extremity is used in both open kinetic chain and closed kinetic chain positions. Examples of closed kinetic chain activities of the shoulder include pushing oneself up from a chair or pass blocking a rushing defender during a football game. Therefore, both open and closed chain exercises should be integrated into a comprehensive rehabilitation program. Examples of upper extremity weight bearing exercises include push-ups with or without modifications and quadruped, prayer, and tripod positions. The rationale for these exercises is to improve proprioception, joint stability, and strength. In addition, a progression from a stable surface to an unstable surface is a standard method of increasing the difficulty of the exercise. Despite the large use of upper extremity weight bearing exercises in the clinical setting little is known about the demand on the shoulder musculature.

The purpose of this study was to examine changes in the deviation of the hand center of pressure and activity of shoulder musculature during three different upper extremity weight-bearing positions of increasing difficulty. The hypothesis to be tested is that with an increasingly compliant surface (less stability), both the mean deviation of the center of pressure and shoulder muscle activity will increase. These findings would support the use of such exercises for the purpose of increasing demand on the shoulder by using increasingly compliant surfaces.

METHODS

Subjects

Electromyographic and kinetic data were recorded from both shoulders of 15 healthy subjects (10 male and 5 female) (age: 30 ± 6 years; height: 171 ± 8 cm; weight: 76 ± 19 kg). Prior to participation, subjects provided informed consent and the study was approved by the Lenox Hill Hospital Institutional Review Board. Subjects were included if they were without a history of upper extremity pathology, had bilateral shoulder strength of 4/5 or greater in all shoulder girdle manual muscle testing positions, and were able to maintain the modified tripod test position for > 20 seconds.

Instrumentation

The subject’s skin was prepared in a standard fashion prior to electrode application to minimize electrical impedance. After cleaning and abrading the skin, bipolar surface electrodes (Ag/AgCl) were placed over the serratus anterior, pectoralis major, upper trapezius, lower trapezius, infraspinatus, anterior deltoid, posterior deltoid, and the lateral head of the triceps muscles using a standardized methodology. Serratus anterior electrodes were placed below the axilla, anterior to the latissimus, and placed vertically over the ribs. The pectoralis major electrodes were positioned one-third of the distance from the greater tuberosity to the xiphoid process with the arm abducted to 90°. Upper trapezius electrodes were located one-third of the distance between the spinous process of the C7 vertebra and the distal clavicle. For the lower trapezius, subjects were lying prone with the arm extended overhead. Electrodes were placed at the level of the inferior angle of the scapula, 2 cm from the vertebral column. Infraspinatus electrodes were placed one-half the distance from the inferior angle to the scapular spine root, 2 cm lateral from the scapula’s medial border. Anterior deltoid electrode placement was two to three finger-breadths below the acromion process, over the muscle belly, in line with the fibers. Posterior deltoid electrode placement was three finger-widths behind the angle of the acromion, over the muscle belly, in line with the fibers. The location of the triceps electrodes was 4 cm distal to the axillary fold. Subjects performed maximal volitional contractions (MVC) against manual resistance to determine the maximum activation for each muscle in a standard manual muscle test position. Muscle activity was recorded at 1000 Hz with an eight-channel telemetry system (Noraxon Telemyo). To compute the linear envelope of the electromyography (EMG), data from each muscle was full-wave rectified and low-pass filtered using a fourth-order Butterworth filter with a 10 Hz cutoff frequency (the same processing was applied to the EMG from each trial described later in the methods). The maximal value for EMG from each muscle (during the appropriate test) was used to normalize the EMG data for analysis.
Test Protocol

The subjects performed three trials for each of the three conditions, for a total of nine trials for both arms. The testing position was a modified tripod position. Subjects were on both knees with one hand on the force plate (Multicomponent Force Plate for Biomechanics, Model #9286, Kistler, Amherst, NY) and the opposite hand on the lower back. To standardize the position, the subjects were instructed to maintain 70º of shoulder flexion, neutral shoulder horizontal abduction/ adduction, and 50º of hip flexion throughout data collection. The tester documented this position with goniometric measurements at the start of each trial. Force plate and EMG data were recorded as subjects held the test position under three different conditions: the subject’s hand resting directly on the force plate (floor) (Figure 1), on a green Thera-Band® (The Hygenic Corp., Akron, OH) Stability Trainer™ (75% deformable under 1000 lb. load) over the force plate, (Figure 2) and on a blue Stability Trainer™ (61% deformable under 1000 lb. load) over the force plate. The order of these positions was randomized for each subject to reduce fatigue or learning effects. Each trial lasted twenty seconds and a one-minute rest was given between trials. Both the dominant and non-dominant arms of each subject were tested. The dominant arm was defined as the arm with which the subjects would throw a ball.

Data Analysis

The average location of the center of pressure for each trial was calculated from the ground reaction forces. The mean deviation from the center of pressure was defined as the average distance of the instantaneous center of pressure from the mean location for the entire trial (Figure 3). This distance gives a region where the center of pressure can be expected to be located. To assess the main effects and any interactions, a 2 (hand dominance) x 3 (test condition) repeated-measures analysis of variance (ANOVA) was performed on this measurement.

The linear envelope (rectified, smoothed) EMG activity was normalized to the maximal activation level determined for each muscle, as described above. Each 20-second trial was divided into three equal parts to examine potential changes in muscle activity over time. The average value over each third of each trial was used for analysis. Repeated-measures ANOVA {2 (hand dominance) x 3 (test condition) x 3 (time)} was then performed to assess the main effects and any interactions of hand dominance, test condition, and test duration on the EMG data from each muscle. Pairwise post-hoc t-tests with Bonferroni corrections were applied where significant main effects were found. Any p values less than 0.05 were considered significant.
RESULTS

Mean Deviation of the Center of Pressure
Statistical analysis revealed a significant main effect of the stability condition on the mean deviation of the center of pressure (p = 0.015). The mean deviation of the center of pressure was lower for the floor condition compared to either of the Stability Trainers (p = 0.04). No difference in the mean deviation existed between the blue and green Stability Trainers (p = 0.977). Additionally, no effect of hand-dominance was found for this measurement (p=0.99).

EMG Data
Statistical analysis revealed a significant main effect of time (p=0.005) on overall muscle activity. Further analysis revealed that the activity of the triceps, serratus anterior, and anterior deltoid muscles increased as each trial progressed (p=0.001, p = 0.025, p = 0.002, respectively) (Table 1), irrespective of the stability condition utilized. A significant condition by muscle interaction (p=0.015) on overall muscle activity also occurred. Activity in the anterior deltoid, lower trapezius, and serratus anterior muscles significantly decreased with decreasing stability (Main Effect of Condition: p = 0.023, p=0.029, p=0.001, respectively), whereas, activity in the triceps significantly increased (p = 0.002) (Table 2).

DISCUSSION

When complementing common open chain therapeutic exercise with closed chain therapeutic exercise during shoulder rehabilitation, the demand placed on the surrounding shoulder musculature during these exercises should be understood. The hypothesis to be tested was that with an increasingly compliant surface, stability would decrease (as evidenced by the increased deviation of the center of pressure) and muscle activity would increase (as evidenced by increased EMG activity). The increase in the mean deviation of the center of pressure indicates that balancing on a foam pad made it more difficult for the subject to maintain the upper extremity in a stable position. The EMG data, however, was less conclusive. Anterior deltoid, upper trapezius, lower trapezius, and serratus anterior muscles demonstrated small decreases in muscle activity with decreasing stability, while the triceps showed a small increase. These findings seem to indicate that the increase in center of

Table 1: Change in shoulder muscle activity (%) over time (beginning of trial to end of trial) irrespective of stability condition.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>% Change (SD)</th>
<th>Time Main Effect (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior Deltoid</td>
<td>13.5 (20.6)</td>
<td>0.002*</td>
</tr>
<tr>
<td>Posterior Deltoid</td>
<td>-0.7 (15.0)</td>
<td>0.652</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>2.5 (19.9)</td>
<td>0.941</td>
</tr>
<tr>
<td>Lower Trapezius</td>
<td>11.9 (21.4)</td>
<td>0.457</td>
</tr>
<tr>
<td>Upper Trapezius</td>
<td>4.5 (20.0)</td>
<td>0.383</td>
</tr>
<tr>
<td>Serratus Anterior</td>
<td>9.1 (17.3)</td>
<td>0.025*</td>
</tr>
<tr>
<td>Pectoralis</td>
<td>10.8 (30.4)</td>
<td>0.115</td>
</tr>
<tr>
<td>Triceps</td>
<td>11.3 (13.5)</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

(*) Significant

Table 2: Effect of stability condition on shoulder muscle activation.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Floor %MVC (SD)</th>
<th>Green %MVC (SD)</th>
<th>Blue %MVC (SD)</th>
<th>Condition Main Effect (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior Deltoid</td>
<td>11.0 (7.2)</td>
<td>9.9 (7.0)</td>
<td>9.7 (7.0)</td>
<td>0.023*</td>
</tr>
<tr>
<td>Posterior Deltoid</td>
<td>12.5 (8.5)</td>
<td>12.1 (9.1)</td>
<td>12.0 (8.3)</td>
<td>0.506</td>
</tr>
<tr>
<td>Infraspinatus</td>
<td>26.3 (10.0)</td>
<td>26.0 (9.9)</td>
<td>25.4 (10.5)</td>
<td>0.656</td>
</tr>
<tr>
<td>Lower Trapezius</td>
<td>16.2 (8.9)</td>
<td>15.4 (9.4)</td>
<td>14.5 (8.2)</td>
<td>0.029*</td>
</tr>
<tr>
<td>Upper Trapezius</td>
<td>4.6 (4.6)</td>
<td>4.3 (4.1)</td>
<td>4.3 (4.1)</td>
<td>0.103</td>
</tr>
<tr>
<td>Serratus Anterior</td>
<td>15.0 (9.3)</td>
<td>13.5 (9.2)</td>
<td>13.0 (9.6)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Pectoralis</td>
<td>8.7 (7.2)</td>
<td>9.6 (8.6)</td>
<td>9.6 (8.1)</td>
<td>0.135</td>
</tr>
<tr>
<td>Triceps</td>
<td>23.1 (11.6)</td>
<td>25.1 (12.8)</td>
<td>25.1 (12.5)</td>
<td>0.002#</td>
</tr>
</tbody>
</table>

(*) EMG activity decreased as task stability decreased.
(#) EMG activity increased as task stability decreased.
pressure deviation produced by balancing on the Stability Trainers was not large enough to require an increase in shoulder muscle activation. Compared to balancing on the floor, balancing on the Stability Trainers most likely changed the position of the hand and the force distribution under it. These changes may have produced the need for more stability at the elbow, hence the increase in triceps activity.

Muscle activity increased throughout each trial, which may indicate muscle fatigue. While muscle fatigue was not explicitly measured, it seems to be a logical conclusion based on the increase in EMG activity over the length of the trial. Physiologically, as a muscle fatigues, more motor units are recruited in order to maintain the specific force output. This results in an increase in action potentials along the muscle (i.e. increased EMG activity). In order to support the weight of the body and maintain stability, more motor units were recruited as the prime support muscles fatigued. Considering that the activity is essentially an isometric exercise, the increase in EMG activity could not have been due to muscle length changes or to a change in contraction velocity.

Few studies have examined upper extremity weight bearing exercises. Lear et al supported incorporating push-up progressions into upper extremity rehabilitation for advanced training of the scapular stabilizers (serratus anterior, upper and lower trapezius muscles) using the push-up “plus” (“plus” indicating active scapular protraction at the end of the up phase). Lear et al chose to vary the exercise by elevating the subject's feet and having the subjects place their hands on a mini trampoline. The authors found that elevating the subject's feet had a significant effect on serratus anterior and upper trapezius muscle activity but no significant effect on lower trapezius activity. Placing the hands on an unstable surface also increased activity of the serratus anterior and upper trapezius but did not increase lower trapezius activity. In contrast, the present study demonstrated an increase in triceps activity while anterior deltoid, upper and lower trapezius, and serratus anterior muscle activity decreased with decreasing stability.

The use of the “plus” phase of the push-up in the Lear et al study is likely to explain the increase in muscle activity of the serratus anterior. In the current study, subjects were not instructed to hold a protracted position of the scapula during the trials. The low activation levels of the serratus anterior may be explained by the difficulty of protracting the scapula in a unilateral, close kinetic chain position. Additionally, changes in surface compliance may not have provided a strong enough stimulus to require an increase in serratus anterior muscle activity.

While the push-up plus position in rehabilitation is one of the greatest activators of the serratus anterior muscle, the purpose for this study was not to determine what muscles would activate the most, but to see what muscles are activated and to what degree during a standard rehabilitation progression of a stable surface to an unstable surface. Clinically, a patient is not typically placed in a closed chain “plus” position when the program is initiated. This position would be more advanced and would be added at a later time with this current progression. In terms of maintaining “neutral” position, human positioning is always a difficult thing to standardize, especially in the shoulder. While the subject maintained the tripod position, verbal feedback was provided from the investigators when the subject began to shift into a retracted or protracted position (retracted was more common). At this point, the subject was cued to maintain their shoulders parallel to the floor.

Uhl et al also sought to determine the demand on shoulder muscles with weight-bearing exercises, and the relationship between increased weight-bearing posture and shoulder muscle activation of the anterior and posterior deltoid, infraspinatus, pectoralis major, and supraspinatus muscles in a progression of seven static upper extremity weight-bearing exercises. The authors found that force, measured through household bathroom scales, significantly increased with an increase in weight-bearing position \((r = 0.97, p < 0.01)\). They also found that muscle activity changed with position and increased with the progression of exercises. Similar to the present findings, the infraspinatus had the highest EMG activity in all conditions. Additionally, the standard push-up had the highest levels of muscle activation, with values significantly higher than the majority of other exercises. Uhl et al concluded that alterations of weight-bearing exercises, by varying the amount of arm support and force, resulted in very different demands on the shoulder musculature. A properly designed shoulder rehabilitation program needs to encompass both open and closed chain thera-

CONCLUSION
The use of unstable surfaces was shown to progressively challenge proprioception and joint stability in the upper extremity. However, providing progressively more unstable surfaces did not lead to a progressive and selective increase in muscle activity. Although activity increased in most muscles throughout the exercise duration, irrespective of the stability condition, increasing the difficulty of the task did not have a similar effect. The compliance of the foam Stability Trainer pads may not have provided enough proprioceptive stimulus to elicit an increase in shoulder muscle activation. Using a less compliant unstable surface may produce the desired increases in shoulder muscle activation; however, further investigation needs to determine a safe and selective progression of treatment.

REFERENCES


ABSTRACT

In this clinical commentary, the use of reactive neuromuscular training (RNT) will be discussed as part of an overall functional rehabilitation program in the treatment of the unstable glenohumeral joint. The RNT program is designed to restore the synchrony and synergy of muscle firing patterns about the shoulder, which are required for dynamic joint stability and fine motor control. Reactive neuromuscular training allows the clinician to bridge the gap between the achievement of clinical based goals and a return to athletic competition. The possible effects of RNT on central nervous system (CNS) programming to establish appropriate reflex responses and functional stability at the glenohumeral joint will be explored. The issues reviewed in this article will highlight the need for future research in this area.

Key Words: reactive neuromuscular training, shoulder instability, central nervous system

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INTRODUCTION
Overhand (baseball, softball) and overhead (swimming, tennis) athletes rely on proper function of the shoulder girdle to allow them to complete the tasks necessary to compete in their respective sports. The shoulder has been measured to move at over 7000 deg/sec and can attain in excess of 16,000 different positions. Due to the inherent instability of the glenohumeral joint and the repetitive nature of many sports, several of these individuals may suffer a shoulder injury at some time in their athletic careers. This clinical commentary attempts to provide a theoretical framework describing the use of reactive neuromuscular training (RNT) as part of a functional exercise progression in the treatment of the overhead and overhand athlete with an unstable shoulder.

The concept of RNT was originally proposed by Voight in 1990. The RNT program is the umbrella heading for a variety of rehabilitation techniques designed to restore dynamic stability and fine motor control at an injured joint. The RNT techniques are intended to augment traditional rehabilitation in a complementary fashion via proprioceptive and balance training in order to promote a more functional return to activity. The main objective of the RNT program is to facilitate the unconscious process of interpreting and integrating the peripheral sensations received by the central nervous system (CNS) into appropriate motor responses. The purpose of this article is to describe the possible effects of RNT on CNS programming and the use of various RNT techniques in the rehabilitation of the unstable shoulder. The unstable shoulder refers to a pathologic condition in which unwanted translation of the humeral head on the glenoid causes pain and dysfunction of the shoulder.

PHYSIOLOGY OF PROPRIOCEPTION
Proprioception is a specialized variation of the sensory modality of touch that encompasses the sensation of joint movement (kinesthesia) and joint position (joint position sense). Knowing exactly where the shoulder girdle is in space and how much muscular effort is required to perform a particular action is critical for the successful performance of overhand activities.

Information about the position and movement of the shoulder is available from the peripheral receptors located in and around the articular structures of the shoulder. These specialized receptors provide information to the CNS regarding joint position sense and movement. The mechanoreceptors do this by converting mechanical deformation into electrical impulses that are sent into the CNS. This proprioceptive information, in turn, via descending efferent pathways, influences joint stiffness, coordinated motor patterns, and reflex activity to provide enhanced joint stability.

Both static and dynamic stabilizers serve to provide support to the normal healthy joint. The role of the capsuloligamentous tissues in the dynamic restraint of the joint has been well established in the literature. While the primary role of these structures is mechanical in nature, by providing structural support and stabilization to the joint, the capsuloligamentous tissues also play an important sensory role by detecting joint position and motion. Vangsness et al described the neural anatomy of the glenohumeral ligaments and labrum in the shoulder. They found Ruffini end organs and Pacinian corpuscles in the superior, middle, and inferior glenohumeral ligaments. However, the glenoid labrum contained only free nerve endings relating to the perception of pain. These authors concluded that any disruption of the ligaments by trauma or surgery can deprive the shoulder of mechanical stability, and may cause a decrease in proprioception because of injury to these afferent neural receptors. Sensory afferent feedback from the receptors in the capsuloligamentous structures projects directly to the reflex and cortical pathways, thereby, mediating reactive muscle activity for dynamic restraint. Sensory information is sent to the CNS to be processed and appropriate motor responses are executed. The efferent motor response that ensues from the sensory information, whether volitional or reflex, simple or complex, is called neuromuscular control.

A role for the muscle spindle has also been elucidated. Diederichsen et al found mechanoreceptors in the coracoacromial ligament, the rotator cuff tendons, the musculotendinous junctions of the rotator cuff, and the joint capsule. Joint rotation will stretch one set of muscles and relax another set of muscles. Since the response of the muscle spindle afferents is known to be a function of muscle length, muscle afferents are able to provide an unconfounded, unidirectional signal of movement.
When an athlete moves the glenohumeral joint into external rotation at 90 degrees of abduction, the stretch of the subscapularis causes firing of the muscle spindles. This information is relayed to the CNS regarding position sense and movement. The exact contribution of each of these tissues has yet to be resolved, but information from all locations provides some position and movement sense throughout the total available range of motion.

**PATHOPHYSIOLOGY**

Following a traumatic subluxation or dislocation, or an atraumatic instability of the glenohumeral joint, disruption to the articular mechanoreceptors inhibits normal neuromuscular reflex joint stabilization. 

Proprioceptive deficits have been uncovered in unstable shoulders in male subjects with unilateral, traumatic, recurrent anterior shoulder instability. 

This partial deafferentation results in a proprioceptive deficit, which contributes to repetitive injuries and the progressive decline of the joint. 

Injuries to the rotator cuff may also lead to a compromise of the afferent feedback from the muscle spindles. Motor programs are adapted to receive specific sensory feedback for the accurate execution of various motor tasks. Injury causes sensory feedback which does not "fit" the existing motor program, causing errors in the normal and coordinated patterns of the muscles and functional joint stability. Ultimately, the individual will be unable to resume high level overhand and overhead activities despite achieving clinical-based goals.

Recognizing the deafferentation of the injured and unstable joint is only half the battle. The rehabilitation specialist must design a program that re-establishes the dynamic functional stability of a joint in hopes of returning the athlete back to competition. Reactive neuromuscular training is employed as part of a functional exercise progression and can be instituted during and following the achievement of clinical-based goals. Before the clinician can utilize these activities, he or she must understand the possible effects RNT has on the CNS.

**SPINAL LEVEL**

Coordinated movement is made possible by the interaction between multiple subsystems located at all levels of the CNS. Three main levels exist in the CNS-the spinal cord, brainstem, and cortical motor areas. The muscle spindle is the key mechanoreceptor at the spinal level. Afferent fibers from the muscle spindles synapse with spinal interneurons, resulting in an efferent response which causes either facilitation or inhibition of the motor neuron – in other words, a stretch reflex. If an external disturbance, such as an increase in load, lengthens the muscle, the discharge rate of the spindle afferents increases. The stretch produced by the load is counteracted by a reflex contraction maintaining the muscle length close to a set value. The stretch reflex allows muscle tone to be regulated quickly and efficiently without direct interaction by higher neural centers.

**MOTOR CORTEX LEVEL**

The highest level of the CNS involved in motor control is the primary motor cortex. The CNS can be likened to a highway, with afferent feedback moving north, and efferent feedback moving south. This information travels in parallel rather than series. Coordinating and planning of complex sequences of movement relies on mechanoreceptor feedback to provide conscious awareness of the joint position and speed of the intended movement. The appreciation of joint position sense at the highest or cognitive level needs to be included in the RNT program. Both active and passive joint repositioning can be utilized to enhance cognitive appreciation of joint position. The repetition of these movements will maximally stimulate the conversion of conscious programming to unconscious programming. To take this one step further, primary motor cortex involvement occurs in activities that last 300 msec or longer. For example, the pitching motion in baseball, from stride foot contact to ball release takes 0.150 second at the youth and high school level and 0.145 second at the college and professional level. When appropriate, repetition of the correct throwing mechanics allows for the motion to be stored as a central command and be performed without the conscious mind. Since faulty throwing mechanics can contribute to increased distraction of the glenohumeral joint and possibly lead to rotator cuff or labral injury, correct throwing mechanics and repetition of this motion must be part of the overall neuromuscular training program.

The perception of joint position and joint movement sense in the shoulder is essential for the placement of the hand in upper limb function. This perception cannot be accomplished without feedback from the mechanoreceptors and central programming from the motor cortex. The
objective of the RNT program is to stimulate the joint and muscle mechanoreceptors to encourage maximal afferent discharge to the appropriate CNS levels. Afferent discharge, will then create an appropriate efferent response at the joint in terms of reflex stabilization and somatosensory perception. Arm movement, reflex stabilization, postural control, and somatosensory perception are not separate events but rather different parts of an integrated action that raises the arm while maintaining balance. A rehabilitation program designed to encourage this feedback will increase the chances of returning an overhead and overhead athlete to their pre-injury level of function.

REHABILITATION

At the present time, no randomized controlled clinical trials exist examining the effects of RNT in the treatment of the unstable glenohumeral joint in the overhead and overhand athlete. However, some guiding principles must be kept in mind when designing the RNT program. The natural progression of these exercises should focus on the continuum of difficulty with respect to the sport or desired activity. These exercises should initially focus on static stabilization of the shoulder joint and progression would then focus on stimulating multiple systems, including vision. Exercises designed to develop dynamic stabilization should progress from bilateral to unilateral, supported to unsupported, and minimal capsular stress to maximal capsular stress. Through therapeutic exercise, the clinician challenges the patient with activities that progress from slow speed to fast speed, from stable surfaces to unstable surfaces, from gradual challenges to sudden challenges, and from simple coordination to complex coordination.

The clinician must be concerned with the kinesthetic input and quality of the movement patterns and not the number of sets and repetitions. It is assumed that the quality of motor control decreases rapidly with the onset of fatigue and the training effects are diminished when the athlete is no longer able to execute the activity. Given that fatigue decreases active and passive joint repositioning, RNT must be fatigue dependent. In order to elicit the appropriate proprioceptive responses, RNT techniques should be applied at the end of the patient’s overall treatment program – when fatigue begins, but the quality of movement is maintained. Obviously, not all shoulder injuries are caused by the onset of fatigue. Research has not demonstrated this clinically, but due to the extremely high repetitions that overhead athletes perform in their respective sport, common sense would dictate that fatigue be addressed in a RNT program. Fatigue plays a major role in the loss of dynamic stability and the possible onset of injury.

The RNT program as part of the functional exercise progression initially focuses on dynamic stabilization at the spinal level. Rhythmic stabilization exercises in the open chain position encourage co-contraction of the musculature about the shoulder, providing a foundation for dynamic neuromuscular stabilization. Taking advantage of the stretch reflex, rhythmic stabilization activities create a change in the desired length of the muscle, resulting in reflex muscular splinting. Efficient co-activation restores the force couples necessary to balance joint forces and increase joint congruency, thereby reducing the loads imparted onto the static structures. These activities can be performed early in the rehabilitation program, first in protected positions such as 90 degrees of elevation, again at 45 degrees of abduction, and eventually at the ends of the available range of motion when the glenohumeral joint is more likely to be unstable. Rhythmic stabilization in the plane of the scapula provides joint congruency and appropriate muscle length tension relationships to protect healing structures immediately post-injury or post-operatively (Figure 1). As the athlete progresses, more challenging positions include 90 degrees of abduction (Figure 2) combined with 90 or more

Figure 1: Rhythmic Stabilization- Patient is sidelying, scapula retracted, upper extremity at side. Therapist moves forearm into ER/IR and pushes scapula toward protrac- tion as patient resists both.
degrees of external rotation, and a similar position in standing (Figure 3-5). Raising the arm above shoulder level can induce increased muscle output and places the compromised glenohumeral joint in a sport-specific position. This position replicates the activities performed by overhand and overhead athletes and will undoubtedly create increased mechanoreceptor output and facilitate dynamic neuromuscular stabilization at the spinal level. Load the system with body weight first and then progress to external resistance. In turn, develop the core of the body before the extremity. The onset of transverse abdominus muscle activity has been documented to occur prior to, or in preparation for, upper extremity tasks.

Simple active and passive joint repositioning, or performing a scapula clock exercise (patient in sidelying, moves the shoulder toward the numbers of a clock, counterclockwise and then clockwise) can enhance somatosensory perception at the motor cortex. The position of the scapula and the scapulothoracic musculature plays a significant role in shoulder stability by providing a stable base of support from which the glenohumeral mus-
icles can fixate and function. The motor cortex also regulates many sports movements that entail controlled acceleration and deceleration. This control makes a case for performing sport-specific plyometric activities near the end of the rehabilitation process when dynamic stability and postural control have been established. Plyometric activities using a weighted ball stimulate unconscious programming as the focus is shifted from holding the arm stable to catching a ball. Movements can be progressed from a supine ball toss and catch in the 90-90 position to kneeling and standing. Eccentric throwing and catching activities enhance joint stabilization while working on deceleration of the upper extremity. These RNT activities are an integral part of the functional exercise progression and will help the athlete return to their pre-injury level of function.

**FUTURE RESEARCH**

Several areas surrounding RNT need to be addressed to further define the usefulness of this rehabilitation approach. Although this paper describes the use of RNT for an unstable shoulder, these techniques may be useful for any shoulder injury or someone with generalized ligamentous laxity. Secondly, randomized controlled clinical trials investigating RNT are needed to validate this approach. Lastly, objective milestones or outcome measures to better progress patients through the RNT program and determine when it is safe to return to athletic competition are recommended.

**CONCLUSION**

In this clinical commentary, the use of reactive neuromuscular training (RNT) is discussed as part of an overall functional rehabilitation program in the treatment of the unstable glenohumeral joint. Normal function of the musculoskeletal system requires a complex coordination of functional joint stability and motor control skills. Following injury to the glenohumeral joint, inappropriate or absent mechanoreceptor discharge can alter neuromuscular control resulting in increased risk for re-injury. An RNT program as part of a sport-specific functional exercise progression can re-establish dynamic stability and neuromuscular control. Clinicians can employ these techniques to target specific levels of the CNS to establish appropriate reflex responses and functional stability at the shoulder. Incorporating the principles of an RNT program in the treatment of an unstable shoulder can bridge the gap between traditional rehabilitation and competition, increasing the chances of an athlete returning to their pre-injury level of function.

**REFERENCES**

ABSTRACT

Background. Jumping and landing tasks are commonly used functional measurement tools to assess lower extremity performance in female athletes. However, few studies have established the number of trials needed to achieve reliability of measurement for evaluating landing mechanics.

Objective. To determine the reliability of peak hip and knee joint angles and peak ground reaction forces during two anterior-posterior unilateral functional tasks performed by young women.

Methods. Sixteen young women (28.5 ± 4.2 years; 162.2 ± 4.8 cm; 59.5 ± 8.1 kg) participated in this investigation. Each participant performed five trials of a 40-cm single leg drop jump and two trials of a ten-repetition, 20-cm, single leg up-down hop task during the same session. Peak hip and knee joint angles, peak vertical ground reaction forces, and ground contact time were measured. Intraclass correlation coefficients (ICC), standard errors of measurement, and 95% confidence intervals were calculated for all variables measured during multiple trials for both tasks.

Results. The five-trial mean ICC values of the drop jump were ≥ 0.75 for all variables. The single and two to four-trial average ICC values yielded good reliability for only some variables. Single-trial and two-trial mean ICC values for the up down test were ≥ .77.

Discussion and Conclusion. The use of five-trial averages for the 40-cm drop jump and a single trial for the 20-cm, up-down hop task showed that for these functional tasks performed by young adult women, reliable measurement of lower extremity landing mechanics can be achieved.

Key Words: reliability, kinematics, landing, kinetics, hop test

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INTRODUCTION

Women athletes experience higher knee joint injury rates compared to men in all sports. Study of lower extremity movement using three-dimensional motion analysis can contribute to the understanding of their knee injuries. Various functional tasks have been described by several investigators for analyzing lower extremity performance, especially when studying landing mechanics in young women. Functional tasks are ideal assessment tools since these tasks integrate several performance components such as joint mobility, muscle strength, power, proprioception, neuromuscular control, balance, and agility. However, most of the lower extremity tasks assessed with motion analysis in previous investigations have been bilateral landing tasks in men, or a combination of men and women. While bilateral tasks provide good information regarding lower extremity performance, these tasks could be missing critical unilateral events that are commonly experienced during sports. In most sports maneuvers, one limb encounters greater loads than the contralateral limb, even during bilateral activities such as cutting and pivoting.

Investigators who conduct motion analysis research rarely report reliability estimates for analyzed tasks. Reliability refers to the reproducibility of the measurement and the ability to minimize measurement error, guaranteeing more accurate data. Investigators who have addressed reproducibility for kinematic variables have primarily assessed bilateral landing tasks in men and women participants combined. Researchers who have assessed reliability of both kinetic and kinematic variables during bilateral jump tasks performed by both sexes combined have calculated intraclass correlation coefficients (ICC's) of 0.89 and above. Reliability values for single-leg tasks can be found in the literature but are limited because the focus has been only for jumping distance and time measures. No reliability values, measurement error estimation, or number of trials needed have been previously assessed for kinematic and kinetic variables during single-leg tasks. Furthermore, performance during single-leg tasks is influenced by external factors such as practice, confidence, fatigue, and number of trials. Greater reliability values have been reported when the average of selected trials was representative of 100% performance effort, which was not achieved until several practice trials had been taken. Several practice trials improve confidence and learning of the task. However, large numbers of trials may also increase the time during data collection and the risk of injuries during task performance. The researchers attest that during development and assessment of research protocols involving human participants, efforts should be made to maximize performance during testing procedures by allowing sufficient warm-up and an adequate number of trials.

The purpose of this investigation was to determine reliability of peak hip and knee joint angles and peak ground reaction forces during two single-leg jumping and landing tasks in healthy young women in order to determine the number of trials needed to achieve acceptable reliability. Data was collected for hip flexion, hip adduction, hip internal rotation, knee flexion, knee valgus, knee external rotation, and vertical ground reaction force measures during a single-leg, 40-cm drop jump and a single-leg, 20-cm up-down hop task. A secondary purpose was to examine potential differences in these measures between the dominant and non-dominant legs.

METHODS

Participants

Sixteen physically active young adult women (age: 28.5 ± 4.2; height: 162.2 ± 4.8 cm; weight: 59.5 ± 8.1 kg) engaged in fitness activities such as jogging and weightlifting participated in this study. Participants were physical therapy students. Exclusion criteria were any history of back or lower extremity surgery and recent injury in the lower back or lower extremities over the past six months. Each participant read and signed an informed consent approved by Texas Woman’s University Institutional Review Board prior to participation. All participants were asked to perform a single hop for distance and a cross-over hop for distance as a screening procedure to obtain clearance for participation. Ability to stick the landing with no report of giving away of the knee during both functional screening tasks were used as criteria for participation and inclusion in the study.

Instrumentation

Participants had 12 retro-reflective markers attached to the skin. These markers were placed over the following
landmarks: bilateral anterior superior iliac spines; the second sacral vertebra; bilateral greater trochanters; bilateral lateral femoral epicondyles; bilaterally, mid-distance between the greater trochanters and lateral femoral epicondyles; bilateral medial femoral epicondyles; bilateral lateral malleoli; bilaterally, mid-distance between the lateral femoral epicondyles and lateral malleoli; bilateral medial malleoli; bilateral calcaneal tuberosities; and bilateral second metatarsophalangeal joints.

The motion analysis system consisted of four digital cameras (60-Hz sampling rate) time-synchronized to one force plate (AMTI, Watertown, MA) (1000 Hz sampling rate). Video data was captured with APAS CapDV software (Ariel Dynamics, Inc. San Diego, CA). Force plate data was recorded with APAS Analog software (Ariel Dynamics, Inc. San Diego, CA). Prior to data collection, space was calibrated according to the manufacturer’s recommendation using a Direct Linear Transformation algorithm with an 8-point, 81.5-cm³ cube. A static trial was captured with each participant standing still, with arms across the chest, to align the joint coordinates to the laboratory recording instruments. After the static trial, the medial femoral epicondyle and medial malleolus markers were removed, to prevent interference between markers and the lower extremities during the performance trials.

Procedures
Weight, height, and the distance between anterior superior iliac spines were measured in each participant. The hip joint center was calculated using the distance between the anterior superior spines and Kwon 3D software (VISOL Inc., Seoul, Korea). Leg dominance was determined by the leg preferred to perform a single hop for distance.

The warm-up protocol consisted of five minutes of cycling at 40 to 60 rpm on a cycle ergometer, 10 half squats, and five continuous vertical jumps. In addition, each participant performed two practice trials with the dominant and non-dominant limbs for both jump tasks. Before participants performed these practice trials, a member of the research team demonstrated both tasks. Two practice trials following demonstration of functional tasks have shown to be sufficient for reliable results during performance of functional tasks. The jump tasks utilized in this investigation consisted of a 40-cm single-leg drop jump (Figure 1) and a ten-repetition, single-leg, 20-cm up-down hop task (Figure 2). These tasks were randomly ordered. A total of five trials for the drop jump and two trials of the up-down task were performed during the same session. The drop jump was selected for its ability to create large eccentric loading on the lower extremities. The up-down task was selected because of its sensitivity, specificity, and accuracy (58%, 97%, and 80%, respectively) in diagnosing dynamic knee instability.

The drop jump (Figure 1) consisted of initially standing with both feet on the 40-cm platform.
and standing on the jumping leg when the command “on your mark” was given. After the command “set”, the participant was instructed to drop down when she felt ready to do so. No additional instructions on how to stand on the drop jump box were given. Each participant was told not to jump vertically, but drop from the box. If the participant performed a vertical jump that was visible to the researchers, the trial was repeated. Each participant was instructed to perform a maximal effort vertical jump upon landing, single-leg, on the center of the force plate. Participants were allowed to use arms freely during all moments of the drop jump. Each participant was allowed to rest as long as she wanted between trials and tasks. Researchers did not allow participants to take less than one minute of rest between trials and tasks.

For the up-down hop task (Figure 2), the participant performed ten repetitive single-leg hops, up to and down from a 20-cm step. As developed by Itoh et al, this task began with each participant standing in front of the 20-cm step. As soon as she felt ready to do so, she jumped single-leg up to and down from the 20-cm step ten consecutive times. The ten consecutive up and down hops comprised one trial. Participants were allowed to use arms freely during all moments of the up-down hop task. Due to the high demands imposed on the lower extremities during this task, participants were required to perform this task only twice. Resting time between trials was similar to the drop jump.

Data Reduction
Joint angles were synchronized and analyzed with Kwon3D 3.1 software (VISOL Inc., Seoul, Korea). Synchronizing events were detected by the moments of initial contact and push-off from the force plate. Joint angles were derived and calculated from the three-dimensional trajectory of the retro-reflective markers. Frequency contents were initially screened using residual analysis and then filtered through a second order, low-pass Butterworth filter (6 Hz). Hip and knee joint angles were defined in the sagittal, frontal, and transverse planes as the first, second, and third rotations, respectively. Local reference frames fixed to the body were defined based on the markers and joint centers for the pelvis, thigh, shank, and the foot. Rotational transformation matrices between linked segments were computed based on the unit vectors of the local frames: pelvis to thigh (hip joint), thigh to shank (knee joint), and shank to foot (ankle joint). Euler angles (orientation angles) were computed from the rotational transformation matrices using the ML-AP-longitudinal axis (XYZ) rotation sequence.

Peak hip flexion, adduction, and internal rotation, and peak knee flexion, valgus, and external rotation were measured. In addition, peak vertical ground reaction forces and ground contact time were assessed. Joint angles and ground reaction force data were exported to Microsoft Excel for analysis. Peak values were identified as the greatest value for all variables from the moment each participant landed on the force plate through the moment she left the force plate into the vertical jump. Peak hip and knee joint angles and peak ground reaction forces were chosen as key variables of interest given these measurements are related to the main injury-causing factors to the knee joint.

From the total of ten continuous hops for the up-down hop task, the first two and last two jumps were excluded to account for acceleration and deceleration during the performance task, averaging the middle six jumps for analysis. This method of exclusion has been shown to help control for performance variability during physical performance tasks including multiple repetitions. The up-down data included the same peak joint angles and kinetic variables as the drop jump. The mean peak values of the middle six hops were considered for analysis.

Data Analysis
All kinematic and kinetic data were screened for normality assumptions and outliers using the Kolmogorov-Smirnov test and histograms. Means, standard deviations, intraclass correlation coefficients (ICC), standard errors of measurement (SEM), and 95% confidence intervals (CI) around the mean and ICC values among the trials in both tasks were calculated for the following measures: hip flexion, hip adduction, hip internal rotation, knee flexion, knee valgus, knee external rotation, vertical ground reaction forces, and contact time during landing. Mean values for peak joint angles and vertical ground reaction forces during the landing phase were used for analysis.

Repeated measures multivariate analyses of variance for mean peak values for five trials of the drop jump and mean peak values for two trials of the up-down task were conducted to determine any significant differences in
peak hip and knee joint angles, ground reaction forces, and contact time between the dominant and non-dominant limbs. Given that no significant differences between dominant and non-dominant legs were found, only the dominant leg was considered for the reliability analysis.

Repeated measures analyses of variance for the dominant limb were performed to develop within-session intraclass correlation coefficients for the averages of two to five trials of the drop jump (ICC [3, k]) and for the two-trial average of the up-down hop task (ICC [3, 2]). Intraclass correlation coefficients for a single trial (ICC [3, 1]) were calculated based on the number of multiple trials by using the following formula: between subjects mean square – error mean square / between subjects mean square + (k-1) error mean square.14

RESULTS

Means, standard deviations, ICC values, SEMs, and 95% CIs for the drop jump and up-down hop task are presented in Tables 1 and 2, respectively. The five-trial averages of the drop jump (Table 1) showed good reliability for all joint angles (ICC ≥ .75) and kinetic (ICC ≥ .86) measures. The single trial and 2, 3, and 4-trial averages yielded good reliability for some of the kinematic and kinetic variables for the drop jump, but not all. The single trial and 2-trial averages for the up-down task (Table 2) showed good reliability for all joint angles (ICC ≥ .77) and kinetic (ICC ≥ .86) measures.

DISCUSSION

The purpose of this investigation was to evaluate the number of trials needed to achieve acceptable reliability when assessing kinematic and kinetic variables during two single-leg tasks in young women. In sports physical therapy, single-leg testing using functional tasks such as the ones used in this investigation help detect muscle weaknesses and knee instabilities to a much greater extent than bilateral functional testing.23 Several components such as practice, familiarization, and confidence of the participant are necessary to perform functional tasks in an optimal manner.16,18 The researcher and sports physical therapist need to be aware how testing procedures could be performed in a more reliable manner and how reliability could be affected by several extraneous variables. Using the average score of multiple trials may improve reliability but may likely also increase the possibility of fatigue and increase the time for data collection and analysis.26 Therefore, a balance between the number of trials to obtain reliable results and feasibility in terms of fatigue and time management is needed during the measurement process.

The results of this investigation suggest that several trials are needed but the number of trials differs according to the specific movement and task analyzed. If tri-planar movements of the hip are considered during the drop jump, four trials are sufficient for reliable results, with hip internal rotation showing the lowest ICC value (0.81). When peak knee joint angles are assessed during the drop jump, five trials are recommended for reliable results in all three planes of motion, with knee flexion exhibiting the lowest ICC value (0.75). During the up-down hop task, a single trial exhibited good reliability for all hip and knee peak joint angles (>0.77). Therefore, these two tasks can be used as functional research tools in this population in a reliable manner for tri-planar hip and knee motion if five trials of the drop jump and a single trial of the ten-repetition up-down task are used to achieve ICC values greater than 0.75.11

Multiple factors could have affected each participant’s performance across trials. One of the most common factors thought to affect reliability of measurements is fatigue during testing procedures.5,12 Fatigue has shown to impair physical performance27 and affect reliability of hop testing.11 Augustsson et al11 assessed test-retest reliability of 11 male participants during a single-hop for distance during non-fatigued and fatigued sessions performed on separate days. The non-fatigue session comprised of performing the single-leg hop task after a warm-up protocol. During the fatigue session, each participant performed the single-leg hop task after a knee extensor fatigue protocol in a dynamometer. Participants performed three trials of a single-leg hop for distance on each of the sessions. The researchers found that within-trials reliability for the non-fatigue session was higher (ICC = 0.98) than the reliability values for the fatigue session (ICC = 0.75). However, when participants were retested three minutes after finishing the fatigue session hop tasks values were similar to the non-fatigue state exhibiting almost full recovery.5 In this investigation, to prevent the possible effects of fatigue on each participant’s performance, each woman was allowed to rest as long as she needed before performing
Table 1. Kinematic and kinetic reliability values for the drop jump

<table>
<thead>
<tr>
<th>Trials</th>
<th>Mean (º) ± SD</th>
<th>Mean (º) ± SD</th>
<th>Mean (º) ± SD</th>
<th>Mean (º) ± SD</th>
<th>Mean (º) ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95% CI (º)</td>
<td>95% CI (º)</td>
<td>95% CI (º)</td>
<td>95% CI (º)</td>
<td>95% CI (º)</td>
</tr>
<tr>
<td>ICC (SEMº)</td>
<td>ICC 95% CI</td>
<td>ICC 95% CI</td>
<td>ICC 95% CI</td>
<td>ICC 95% CI</td>
<td>ICC 95% CI</td>
</tr>
<tr>
<td>Kinematics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single Trial</td>
<td>55.13 ± 12.06</td>
<td>54.66 ± 12.23</td>
<td>54.41 ± 11.85</td>
<td>54.12 ± 11.80</td>
<td>53.76 ± 12.04</td>
</tr>
<tr>
<td>2-Trial Avg</td>
<td>45.38-64.88</td>
<td>47.47-61.85</td>
<td>49.22-59.60</td>
<td>50.11-58.13</td>
<td>50.42-57.10</td>
</tr>
<tr>
<td>3-Trial Avg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-Trial Avg</td>
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<td></td>
</tr>
<tr>
<td>5-Trial Avg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip flexion</td>
<td>.83a (4.97)</td>
<td>.91 (3.67)</td>
<td>.95 (2.65)</td>
<td>.97 (2.04)</td>
<td>.98 (1.70)</td>
</tr>
<tr>
<td></td>
<td>.55-.94</td>
<td>.71-.97</td>
<td>.88-.98</td>
<td>.93-.99</td>
<td>.95-.99</td>
</tr>
<tr>
<td></td>
<td>13.47 ± 5.19</td>
<td>11.74 ± 4.87</td>
<td>10.95 ± 5.04</td>
<td>10.61 ± 5.20</td>
<td>10.43 ± 5.30</td>
</tr>
<tr>
<td>Hip adduction</td>
<td>.75a (2.60)</td>
<td>.86 (1.82)</td>
<td>.93 (1.33)</td>
<td>.93 (1.38)</td>
<td>.95 (1.19)</td>
</tr>
<tr>
<td></td>
<td>.39-.91</td>
<td>.56-.95</td>
<td>.84-.98</td>
<td>.85-.98</td>
<td>.88-.98</td>
</tr>
<tr>
<td>Hip internal rotation</td>
<td>.48a (6.66)</td>
<td>.65 (5.71)</td>
<td>.73 (4.28)</td>
<td>.81 (3.35)</td>
<td>.88 (2.63)</td>
</tr>
<tr>
<td></td>
<td>-.05-.80</td>
<td>-.10-.89</td>
<td>.33-.91</td>
<td>.59-.93</td>
<td>.73-.95</td>
</tr>
<tr>
<td>Knee flexion</td>
<td>.09a (10.28)</td>
<td>.16 (6.25)</td>
<td>.29 (4.83)</td>
<td>.61 (3.78)</td>
<td>.75 (3.22)</td>
</tr>
<tr>
<td></td>
<td>-.44-.58</td>
<td>-.161-.73</td>
<td>-.73-.75</td>
<td>.12-.86</td>
<td>.46-.91</td>
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<tr>
<td>Knee valgus</td>
<td>.34a (3.59)</td>
<td>.51 (2.51)</td>
<td>.73 (1.77)</td>
<td>.84 (1.38)</td>
<td>.86 (1.26)</td>
</tr>
<tr>
<td></td>
<td>-.20-.73</td>
<td>-.52-.84</td>
<td>.34-.91</td>
<td>.63-.94</td>
<td>.70-.95</td>
</tr>
<tr>
<td>Knee external rotation</td>
<td>.74a (3.97)</td>
<td>.85 (2.60)</td>
<td>.93 (1.87)</td>
<td>.96 (1.49)</td>
<td>.97 (1.30)</td>
</tr>
<tr>
<td></td>
<td>.36-.91</td>
<td>.53-.95</td>
<td>.82-.97</td>
<td>.90-.98</td>
<td>.94-.99</td>
</tr>
<tr>
<td>Kinetics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRF (BW)</td>
<td>4.79 ± .89</td>
<td>4.66 ± .81</td>
<td>4.64 ± 1.04</td>
<td>4.74 ± 1.07</td>
<td>4.27 ± 1.00</td>
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<tr>
<td></td>
<td>3.67-5.91</td>
<td>3.86-5.46</td>
<td>3.89-5.41</td>
<td>4.18-5.30</td>
<td>3.75-4.79</td>
</tr>
<tr>
<td></td>
<td>.59a (57)</td>
<td>.74 (41)</td>
<td>.86 (40)</td>
<td>.93 (28)</td>
<td>.93 (27)</td>
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<tr>
<td></td>
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<td>.15-.92</td>
<td>.65-.95</td>
<td>.84-.98</td>
<td>.85-.98</td>
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<tr>
<td>Contact time (seconds)</td>
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<td>.03-.05</td>
<td>.03-.04</td>
<td>.03-.04</td>
<td>.04-.04</td>
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<tr>
<td></td>
<td>.70a (.003)</td>
<td>.82 (.004)</td>
<td>.85 (.003)</td>
<td>.91 (.002)</td>
<td>.94 (.002)</td>
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<tr>
<td></td>
<td>.26-.90a</td>
<td>.42-.95</td>
<td>.61-.95</td>
<td>.78-.97</td>
<td>.86-.98</td>
</tr>
</tbody>
</table>

SD: standard deviation; ICC: Intraclass Correlation Coefficient; SEM: standard error of measurement estimated using SD of the score; 95% CI: confidence interval based on SEM; GRF: ground reaction forces/times body weight. a Intraclass correlation coefficients for a single trial (ICC [3, 1]) were calculated based on the number of multiple trials used by the following formula: between subjects mean square – error mean square / between subjects mean square + (k-1) error mean square (Figure 3).14
Table 2. Kinematic and kinetic reliability values for the up-down hop test

<table>
<thead>
<tr>
<th>Trials</th>
<th>Mean (<em>) ± SD 95% CI (</em>)</th>
<th>Mean (<em>) ± SD 95% CI (</em>)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICC (SEMº) ICC 95% CI</td>
<td>ICC (SEMº) ICC 95% CI</td>
</tr>
<tr>
<td><strong>Kinematics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Single Trial</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip flexion</td>
<td>.95º (1.69) 36.95 ± 7.56</td>
<td>.97 (1.28) 38.69 ± 7.37</td>
</tr>
<tr>
<td></td>
<td>.82-.99 36.34-42.96</td>
<td>.90-.99 36.19-41.19</td>
</tr>
<tr>
<td>Hip adduction</td>
<td>.93º (1.96) 9.72 ± 7.42</td>
<td>.97 (1.24) 9.14 ± 7.17</td>
</tr>
<tr>
<td></td>
<td>.76-.98 5.87-13.57</td>
<td>.87-.99 6.71-11.58</td>
</tr>
<tr>
<td>Hip internal rotation</td>
<td>.97º (1.30) 7.59 ± 7.53</td>
<td>.98 (1.05) 7.78 ± 7.42</td>
</tr>
<tr>
<td></td>
<td>.89-.99 5.04-10.15</td>
<td>.94-1.0 4.57-9.84</td>
</tr>
<tr>
<td>Knee flexion</td>
<td>.77º (2.04) 51 ± 4.25</td>
<td>.87 (1.94) 49.55 ± 5.39</td>
</tr>
<tr>
<td></td>
<td>.36-.94 47.01-54.99</td>
<td>.53-.97 45.74-53.36</td>
</tr>
<tr>
<td>Knee valgus</td>
<td>.94º (1.46) 7.49 ± 5.97</td>
<td>.97 (0.85) 6.25 ± 4.88</td>
</tr>
<tr>
<td></td>
<td>.79-.99 4.63-10.36</td>
<td>.88-.99 4.59-7.90</td>
</tr>
<tr>
<td>Knee external rotation</td>
<td>.93º (2.14) 10.12 ± 8.09</td>
<td>.97 (1.37) 8.96 ± 7.93</td>
</tr>
<tr>
<td></td>
<td>.76-.98 5.92-14.32</td>
<td>.86-.99 6.27-11.65</td>
</tr>
<tr>
<td><strong>Kinetics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GRF (BW)</td>
<td>.88º (.20) 2.67 ± .57</td>
<td>.94 (.10) 2.80 ± .39</td>
</tr>
<tr>
<td></td>
<td>.65-.96 2.29-3.06</td>
<td>.79-.98 2.61-2.99</td>
</tr>
<tr>
<td>Contact time</td>
<td>.04 ± .03</td>
<td>.07 ± .02</td>
</tr>
<tr>
<td>(seconds)</td>
<td>.03-.05</td>
<td>.07-.08</td>
</tr>
<tr>
<td></td>
<td>.97º (.01) .04 ± .03</td>
<td>.99 (0.0) .07 ± .02</td>
</tr>
<tr>
<td></td>
<td>.91-.99</td>
<td>.95-1.0</td>
</tr>
</tbody>
</table>

SD: standard deviation; ICC: Intraclass Correlation Coefficient; SEM: standard error of measurement estimated using SD of the score; 95% CI: confidence interval based on SEM; GRF: ground reaction forces/times body weight. * Intraclass correlation coefficients for a single trial (ICC [3, 1]) were calculated based on the number of multiple trials used by the following formula: between subjects mean square – error mean square / between subjects mean square + (k-1) error mean square (Figure 3).
the next trial. Although sufficient rest was allowed between trials, the possibility of cumulative fatigue throughout the testing session could not be dismissed.

The 60 Hz sampling rate could have introduced variability into the measurement of such fast movements. However, the high frequency components for the drop jump and up-down jump tasks, especially during impact with the force plate capable of introducing such variability, were filtered through the 6 Hz low-pass filter. Therefore, the 60 Hz sampling rate with a 6 Hz Butterworth filter seems reasonable given the data of interest were peak hip and knee joint moments during the ground contact phase.

Perry et al18 assessed the number of trials during hop tests needed for reliable distance and height measures in individuals with anterior cruciate ligament deficiency and ACL reconstruction. The researchers reported that for the single-hop for distance and triple crossover tasks, a minimum of 10 trials ensured 99% of maximum performance effort values in both tasks. Similarly, a minimum of 15 trials were needed to ensure 97.6% of maximum performance effort during the vertical single-leg jump. The number of trials needed in a research protocol are important if accurate results are expected and if the trials are indeed representative of maximum performance.18 The results of the current investigation showed results similar to Perry et al18 in terms of total number of jumps needed for acceptable reliability.

Previous investigations evaluating landing performance in young women during bilateral landing tasks used three to five trials and reported good ICC values for knee joint kinematics and kinetics without a comprehensive warm-up.7,8 No investigations of reliability for kinematic and kinetic variables have reported SEM or 95% CI values.7,8 These statistics indicate the trial-to-trial error expected in the functional tasks and determine the range for a population's true score.12 Known error scores help the researcher assess whether changes in participants' performance are really true changes or are within the range of error for the specific measurement.12 In addition, these statistics allow observation of the improvements in reliability values with greater number of trials (Tables 1-2).

Typically, only the dominant leg is used as reference for biomechanical analysis and to make group comparisons when evaluating lower extremity landing mechanics. The findings of this investigation suggest that in non-injured young women, either the dominant or non-dominant leg may be considered as reference for analysis. These findings are consistent with other investigations in which no statistically significant differences between the dominant and non-dominant legs were found for lower extremity joint angles,25 muscle strength,21 and endurance28 during physical performance tasks.

Several practical applications exist that could be derived from this investigation. First, the process of familiarization and warm-up should be included in testing protocols to ensure near maximum performance. In addition, the use of multiple trial or multiple repetition averages enhances the reliability of the measurements and reduces the absolute measurement error. The protocol used in this investigation was acceptable for reliably testing single-leg landing mechanics in young women. Because ligamentous injuries have been shown to occur mainly during unilateral tasks, single-leg functional tasks should be incorporated into biomechanical assessments of performance.

CONCLUSIONS
The results of this investigation revealed that the average of five trials of the drop jump and one trial of the 10-repetition up-down task are recommended to obtain good trial-to-trial reliability for hip and knee peak joint angles and ground reaction forces. Additionally, in healthy non-injured individuals either dominant or non-dominant legs could be used to assess landing mechanics.

REFERENCES


