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Shoulder Antagonistic Strength Ratios: A Comparison between College-Level Baseball Pitchers and Nonpitchers

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The purpose of this study was to investigate the shoulder strength ratios obtained from college-level baseball pitchers and age- and sex-matched nonpitchers. Shoulder flexion/extension and external/internal rotation strength ratios were assessed in 10 pitchers and 9 nonpitchers. Speeds selected for testing were 180 and 300°/sec on the Cybex II.® Results indicated that both pitchers and nonpitchers generated greater peak torque values for the extensors and internal rotators than for the flexors and external rotators of the shoulder. A comparison of shoulder strength ratios between a pitcher's throwing arm and his nonthrowing arm was statistically significant ($p < 0.05$) for shoulder external/internal rotation at the speeds of 180 and 300°/sec. A comparison of shoulder strength ratios between pitchers and nonpitchers on the nondominant arm was not statistically significant for any of the speeds or directions tested. A comparison of the shoulder strength ratios between pitchers and nonpitchers on the dominant arm was statistically significant ($p < 0.05$) for all directions and speeds tested. The relationship between shoulder muscle imbalance and injury was discussed.

Baseball pitching is a complex, highly skilled, repetitive task which subjects the throwing shoulder to maximal stresses. Because of the special physiological demands placed on the shoulder, it is not surprising that shoulder injury is a common occurrence among baseball pitchers.[1,3,4,22] Although muscle imbalance and lack of normal flexibility about the shoulder have been identified as possible predisposing factors to shoulder injury in pitchers, little research data of any kind has been published.[5,6,18]

Limited range of motion in the shoulder and temporary changes of habitual style of delivery may be a potential cause of injury to the pitching arm.[1]King et al.,[15] in an analysis of the pitching arms of baseball pitchers, noted characteristic range of motion values such that in relation to the opposite arm, there was generally an increase in active shoulder external rotation and a decrease in active internal rotation. In a later study, Tullos and King[22] further noted that increases in active shoulder external rotation can be produced merely by warm-up activities that involve that movement.

Naturally occurring muscle imbalances have been investigated across several joints.[23,25] Mottice[16] documented a naturally occurring muscle imbalance between the internal and external rotators of the shoulder. He found that the internal rotators always generated greater torque.

Training-induced muscle imbalances have also been studied, particularly at the knee joint.[20] Parker et al.[19] demonstrated that the hamstrings/quadriceps ratio differs between athletes and nonathletes. Davies et al.[10] reported that professional football players have lower hamstring to quadriceps ratio than normals. This apparent disparity between opposing muscle groups is theorized to be the physiological response of muscle tissue to specific training demands.

The act of prolonged and repetitive throwing would appear to lead to certain training-induced effects on specific muscle groups in the shoulder.

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In order to understand the muscular demands required, one must first understand the complex biomechanics involved in the act of pitching. Pitching biomechanics have been described extensively in the literature.[1,22] Three distinct phases of pitching can be identified: wind-up, acceleration, and follow-through. Jobe et al.,[12,13] using dynamic electromyography and high speed photography, recorded muscle activity throughout each of these three phases.

Muscles responsible for the wind-up phase of pitching are the humeral external rotators; posterior deltoid, infraspinatus, and teres minor, shoulder abductors; middle deltoid, supraspinatus, and the shoulder flexors; anterior deltoid, coracobrachialis, and pectoralis major. The acceleration phase is initiated by muscle contraction of the shoulder internal rotators; pectoralis major and minor, subscapularis, teres major, latissimus dorsi and anterior deltoid. Jobe et al.[12] discovered that after the initial burst of muscular activity serving to internally rotate the shoulder, the rest of the acceleration phase of the pitching cycle is without muscle activity. This phenomenon has been partially explained by Toyoshima et al.[21] who state that 50% of throwing speed is the result of sequential body rotations, while the remainder is the result of muscular activity in the arm. Interestingly, Jobe et al.[12] reported that the follow-through phase is the most active phase of the pitching act. He stated that the subscapularis is internally rotating the shoulder while the remaining rotator cuff and deltoid muscles are probably firing eccentrically in an attempt to decelerate the arm in space.

Coleman[5,6] studied the strength characteristics of professional baseball pitchers in order to examine the effects of in-season strength training. He discovered a muscle asymmetry between antagonistic muscle groups about a pitcher's shoulder between a pushing and a pulling motion. However, the testing protocol used in the Coleman study did not isolate the movement of the shoulder to the transverse and sagittal planes.

Although naturally occurring and training-induced muscle strength differences have been described, data is needed to provide information on shoulder strength ratios in both pitching and nonpitching groups. This data would provide a valuable tool for athletic screening of pitchers, and for shoulder rehabilitation in both pitching and nonpitching populations.

The purpose of this study was to investigate shoulder strength ratios obtained from college-level baseball pitchers, and age- and sex-matched nonpitchers. Specifically, dominant and nondominant shoulder strength ratios were compared between a pitching and nonpitching population. In addition, dominant shoulder strength ratios were compared to nondominant shoulder strength ratios within both populations.

METHOD

Subjects

Fifteen college level baseball pitchers were compared with 13 age-matched nonpitchers. All subjects were male between the ages of 18 and 25. Both sample groups were asked to fill out a questionnaire on the day of testing. This information was used to describe the subject population.

A pitcher was included in this study if he: *1)* had pitched competitively for the last 5 years, and within the last 6 months he had not missed more than 20% of practice and/or playing time due to injury; *2)* had no history of surgery on either upper extremity; and *3)* subjectively reported on the day of testing that he was currently pitching at least 80% of his performance before injury.

A nonpitcher was used in this study if he: *1)* had no history of surgery on either upper extremity, and *2)* reported no musculoskeletal complaints in either upper extremity, neck or chest on the day of testing.

Instrumentation

Torque output values produced at the shoulder were collected on an Apple II® (Apple Computer Inc., 20525 Mariani Ave., Cupertino, CA) computer interfaced with a Cybex II® (Cybex, Division of Lumex, Inc, 2100 Smithtown Ave., Ronkonkoma, NY 11779) dynamometer. Additional Cybex equipment required for upper extremity testing were the Upper Body Testing and Exercise Table (UBXT), dual channel recorder, upper extremity adaption equipment, and velcro straps for stabilization. The Cybex II dynamometer was calibrated to the manufacturer's specifications before testing began.[8,9]

The Apple II computer allowed for ease of data collection, data storage, and graphic display of torque curves. The computer was calibrated to the Cybex dynamometer during each subject's evaluations. The reliability of the computer was assessed by comparing the torque output values recorded by the computer to those values measured on the strip chart recorder. The Apple II Cybex software package was made available through Omni Computer Systems (Omni Computer Systems, 3075 Citrus Circle, Suite 240, Walnut Creek, CA 94598).

Procedure

On the day of testing each subject completed a human consent form and filled out a brief questionnaire. The questionnaire elicited demographic information, medical history, and the nature and extent of their activities requiring upper extremity strength. Pitchers were specifically asked about the degree of their participation in pitching.

After completion of the questionnaire each subject performed four active stretching exercises for the upper extremities. Each stretch was performed twice with each stretch being held for a count of 10 sec. One investigator monitored the subjects during stretching in order to ensure that each stretch had been performed adequately. Active stretches were selected instead of passive stretches to decrease the chance of injury to the subjects.

Testing Protocol

The motions tested on both shoulders of each subject included shoulder extension/flexion and shoulder internal/external rotation. The order of testing of these motions on each subject was left shoulder extension/flexion, right shoulder extension/flexion, left shoulder internal/external rotation, and right shoulder internal/external rotation. Standard Cybex protocol was used for both shoulder extension/flexion in the supine position and shoulder internal/external rotation.[9] Shoulder extension/flexion movements were blocked at 180° of flexion and 0° of extension. Shoulder internal/external movements were blocked at 60° of both shoulder internal and external rotation. Stabilization to prevent hip and trunk rotation was provided by two velcro straps. One strap was placed across the anterior superior iliac spines to stabilize the pelvis. The other strap was placed across the rib cage at the level of the xiphoid process to stabilize the trunk. These testing positions were chosen because they most closely approximated the pitching motion while still allowing for trunk stabilization.

Cybex Warm-up and Testing

During Cybex warm-up and testing, each subject was isolated from the other participants in the study in order to reduce the competition effect between subjects. Each subject was given a brief explanation of isokinetic testing and complete instructions concerning the test. Subjects were encouraged to give maximum effort on every repetition in both directions. Each subject was placed upon the UBXT and positioned such that the axis of rotation of the shoulder joint was aligned with the axis of rotation of the dynamometer.

Each subject was first instructed to perform a practice series of submaximal contractions on the Cybex at 120°/sec for 10 repetitions in order to warm-up the shoulder and to familiarize the subject with accommodative resistance. Subjects were instructed to "just catch the speed of the machine."

Subjects were then instructed to perform a practice building set of 7 repetitions at 180°/sec. Each subject began by "catching the machine," and then progressively worked against the machine until he reached his maximum at repetition 7. Evaluation at the 180°/sec speed consisted of one trial of 7 repetitions. Each subject was allowed a 2-minute rest between speed changes.

Each subject was then instructed to perform a practice series of submaximal contractions at 300°/sec for 10 repetitions in order to become familiar with the higher speed setting. Each subject then performed another practice building set of 7 repetitions at 300°/sec speed setting. Evaluation at the 300°/sec speed consisted of one trial of 10 repetitions.

Both shoulders were warmed up and tested in the same manner for both motions tested. During evaluations, each subject was encouraged to move his arm as fast and as hard as possible in both directions. The 300°/sec speed was selected because it is the highest speed available on the Cybex. The slower speed of 180°/sec was chosen to allow the subjects more time to generate greater torque outputs.

After Cybex testing, each subject's active range of motion was measured for both shoulders with a standard 360° goniometer. Each subject was positioned in the same manner as on the Cybex in order to measure active end range values for shoulder extension/flexion and shoulder internal/external rotation.

ANALYSIS

Means and standard deviations were calculated for the subjects' demographic data, for all range of motion measurements, and for all strength ratios at the two different speeds. Strength ratios were calculated automatically by the computer. The greatest extension peak torque generated during the trial was divided into the greatest flexion peak torque output generated during the trial. This ratio represented the percentage of maximal extension torque output as compared with maximal flexion torque output. The external rotation/internal rotation ratio was calculated in the same manner with internal rotation peak torque output being divided into external rotation peak torque output to obtain the percentage.

Paired two-tailed *t*-tests ($p < 0.05$) were used to compare: *1)* pitchers' dominant shoulder strength ratios to pitchers' nondominant shoulder strength ratios at the speeds 180°/sec and 300°/sec, and *2)* nonpitchers' dominant shoulder strength ratios to nonpitchers' nondominant shoulder strength ratios at the speeds 180°/sec and 300°/sec.

Unpaired two-tailed *t*-tests ($p < 0.05$) were used to compare: *1)* dominant shoulder strength ratios of pitchers to dominant shoulder strength ratios of nonpitchers at the speeds 180°/sec and 300°/sec, and *2)* nondominant shoulder strength ratios of pitchers to nondominant shoulder strength ratios of nonpitchers at the speeds 180°/sec and 300°/sec.

RESULTS

Fifteen pitchers and 13 nonpitchers were tested. Five of the pitchers were excluded for the following reasons: one subject had elbow surgery, two subjects experienced pain during testing, and two subjects' information was incomplete because of computer operator error. Four of the nonpitchers were excluded because of computer operator error. Thus, a total of 10 pitchers and 9 nonpitchers were used in the analysis of data.

Means, standard deviations, and ranges of the subjects' age, height, and weight are listed in Table 1. There were eight right-handed and two left-handed pitchers; there were eight right-handed and one left-handed nonpitchers.

TABLE 1
Demographics

	Pitchers		Nonpitchers	
	Mean	SD	Mean	SD
Age (years)	19.4	1.17	20.78	2.11
Height (inches)	72.3	1.57	69.78	3.19
Weight (pounds)	175.5	15.28	162.22	30.26

Values for shoulder range of motion are depicted in Figure 1. Means and standard deviations for the shoulder strength ratios of both pitchers and nonpitchers for flexion/extension and external/internal rotation are depicted in Figures 2, 3, 5 and 6.

Within Populations

The difference in shoulder strength ratios between a pitcher's throwing arm and his nonthrowing arm was statistically significant for shoulder external/internal rotation at the speeds of 180°/sec ($p < 0.05$), and 300°/sec ($p < 0.05$) (Fig. 2). The difference between a nonpitcher's dominant arm and his nondominant arm was statistically significant for shoulder flexion/extension at 300°/sec ($p < 0.05$) (Fig. 3).

Figure 4 lists the factors influencing shoulder strength ratios changes on the dominant side as compared to the nondominant side within the population of pitchers. Of the three possible reasons for the ratio change, the majority of pitchers' rotation ratios dropped because shoulder external rotation was weaker in the throwing arm as compared to the nonthrowing arm. In addition, five of the pitchers' rotation ratio dropped at the 180°/sec speed not only because of the fact that external rotation was weaker in the throwing arm, but internal rotation was also stronger in the throwing arm as compared with the nonthrowing arm. The increase in internal rotation strength was not as pronounced at the 300°/sec speed.

Between Populations

A comparison of shoulder strength ratios between pitchers and nonpitchers on the nondominant arm was not statistically significant for any of the directions and speeds tested (Fig. 5). A comparison of the shoulder strength ratios between the two populations on the dominant arm were significant for shoulder flexion/extension at 180°/sec ($p < 0.01$), shoulder flexion/extension at 300°/sec ($p < 0.01$), shoulder external/internal rotation at 180°/sec ($p < 0.05$), and shoulder external/internal rotation at 300°/sec ($p < 0.05$) (Fig. 6).

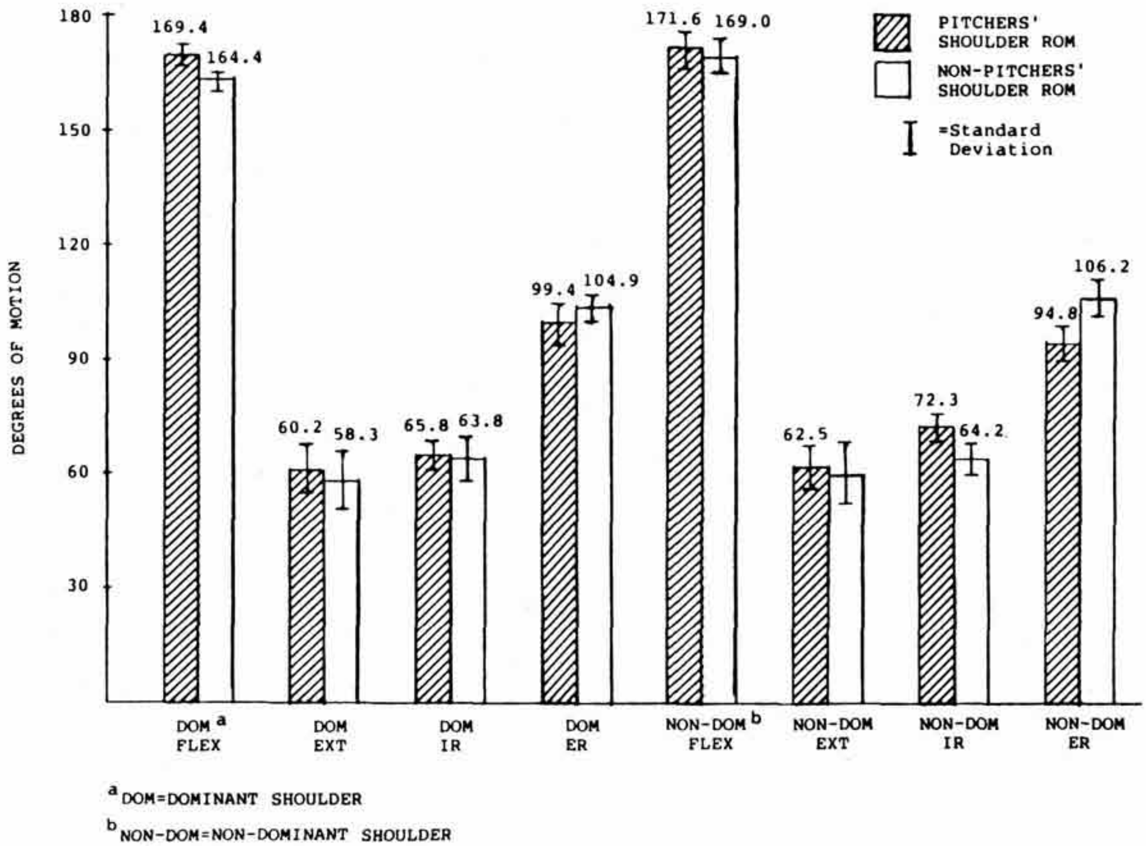

Fig. 1. *Shoulder range of motion: comparison between pitchers and nonpitchers.*

DISCUSSION

Shoulder Range of Motion

Evaluation of shoulder range of motion values in this study confirmed earlier observations reported by King et al.[15] A comparison of the pitchers' dominant to nondominant arms demonstrated an increase in external shoulder rotation with a concomitant decrease in internal shoulder rotation on the dominant side. Similar internal and external rotation changes were not observed in the nonpitching population. It is reasonable to assume, therefore, that this alteration of shoulder external and internal range of motion noted only in the dominant (throwing) arm of the pitchers is related to the pitching act. This alteration of shoulder range of motion may be due to repetitive stretching incurred by the internal rotators during the acceleration phase of a pitch when the shoulder is placed in extreme external rotation.

Shoulder Strength Ratios

Both the pitchers and nonpitchers generated greater peak torque values for the internal rotators and extensors of the shoulder as compared to the respective external rotators and flexors. It would appear, therefore, that there is a naturally occurring muscle imbalance between antagonistic muscle groups of the shoulder.

DePalma et al.[11] stated that the volume of the subscapularis muscle equals that of the infraspinatus and teres minor combined. This illustrates the relatively small cross-sectional area of muscle mass of the external rotators when compared to that of only one internal rotator. Our findings that external rotation is weaker than internal rotation is consistent with Mottice's[16] findings on dominant shoulder strength ratios in a normal male adult population. Mottice hypothesizes that the rotation imbalance is due to a comparision of the cross-sectional area of muscle mass responsible for shoulder internal and external rotation, respectively. The overall cross-sectional area of the internal rotators clearly exceeds that of the external rotators. Consequently, the internal rotators would be expected to have greater force capabilities.

Flexion/extension imbalance may also be explained by comparison of the cross-sectional area

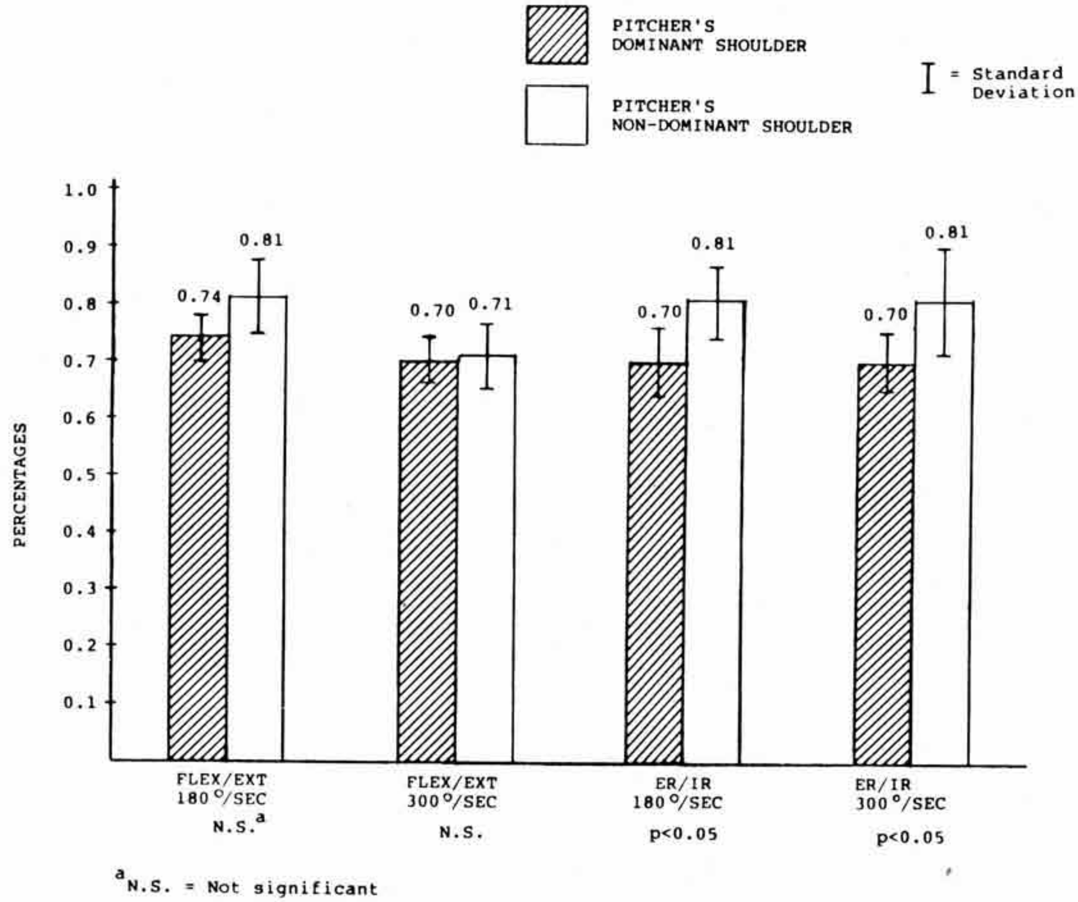

Fig. 2. *Shoulder strength ratios: comparison of pitchers' dominant shoulders to their nondominant shoulders.*

of muscle mass responsible for shoulder extension and shoulder flexion. Knowledge of shoulder anatomy suggests that the shoulder extensors do indeed exceed the shoulder flexors in muscle mass. Thus, the shoulder extensors would likewise be expected to create greater force capabilities than the shoulder flexors.

Within Populations

Comparison of pitchers' throwing arms to their nondominant arms revealed that the shoulder rotation strength ratio significantly decreased in the pitchers' throwing arms, signaling a greater disparity in external and internal rotation when compared to their nonthrowing arms. However, there was no significant difference between arms in the shoulder strength ratios of flexion/extension. There are several possible explanations for the pitchers' decrease in external rotation strength and concomitant increase in shoulder internal rotation strength in comparison with the nonthrowing arm. There may be an imbalance of training of the two rotations in the act of pitching. Failure to submit antagonistic muscle groups to similar degrees of stress may result in a muscle imbalance.

Another explanation for a weakening of the external rotators in the throwing arm of pitchers has been suggested by both Jobe and Pappas.[14,18] They theorize that athletes who engage in repetitive overhead throwing motion may display weakness and atrophy of the infraspinatus muscle due to suprascapular nerve entrapment.

According to Jobe,[12] the external rotators are most active during the follow-through phase of pitching, firing eccentrically to slow the arm down in space. The major role of the external rotators in pitching, therefore, appears to be in stabilization and protection of the glenohumeral joint from excessive trauma as the pitcher releases the ball at up to speeds of 100 mph. Results from this study imply that a naturally occurring muscle imbalance exists; shoulder flexors and external rotators are weaker than the shoulder extensors and internal rotators, respectively. Furthermore, this natural imbalance appears to be increased by the effects of long-term pitching. For whatever

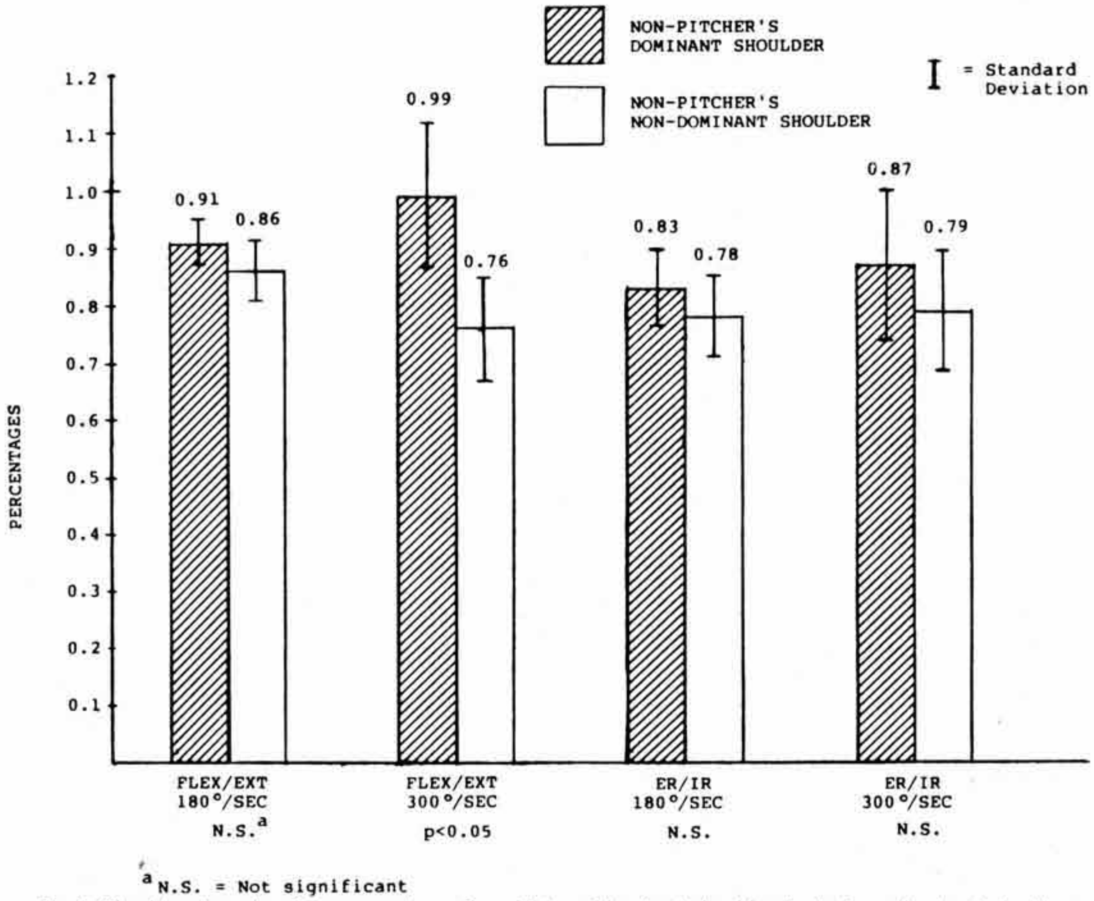

Fig. 3. *Shoulder strength ratios: comparison of nonpitchers' dominant shoulders to their nondominant shoulders.*

reason, imbalance of training or stretching of the suprascapular nerve, the increased shoulder muscle imbalance might be a factor in shoulder injury. With the increased muscle rotation asymmetry, the external rotators may have decreased their capability of providing adequate protection to the unstable glenohumeral joint from the abnormal stresses of pitching. The repeated microtrauma to the joint may result in an overuse, over-demand injury. It is possible, therefore, that the incidence of shoulder injury may be reduced if pitchers participated in strength training programs specifically designed to increase shoulder external rotation strength.

Between Populations

Analysis of the data revealed no significant difference between the nondominant shoulder strength ratios of pitchers and nonpitchers. These results imply that the nondominant shoulder for either group was not submitted to any unusual type of muscular training or demands which would cause shoulder strength ratios to differ across populations.

Comparison of the pitchers' dominant shoulder strength ratios to the nonpitchers' dominant shoulder strength ratios was statistically significant for all directions and speeds tested. These results further suggest the act of pitching does indeed place special demands on a pitcher's shoulder as compared with the demands placed on a nonpitcher's shoulder.

Limitations of Study

This study comparing the shoulder antagonistic strength ratios of pitchers to nonpitchers was limited to a small sample of convenience. The results revealed significant strength imbalances. However, further research using a larger subject population for both groups is necessary before this information can be generalized to represent normative data.

Although the Cybex is a reliable instrument for measuring dynamic strength,[9] pitching requires a sequence of highly coordinated neuromuscular

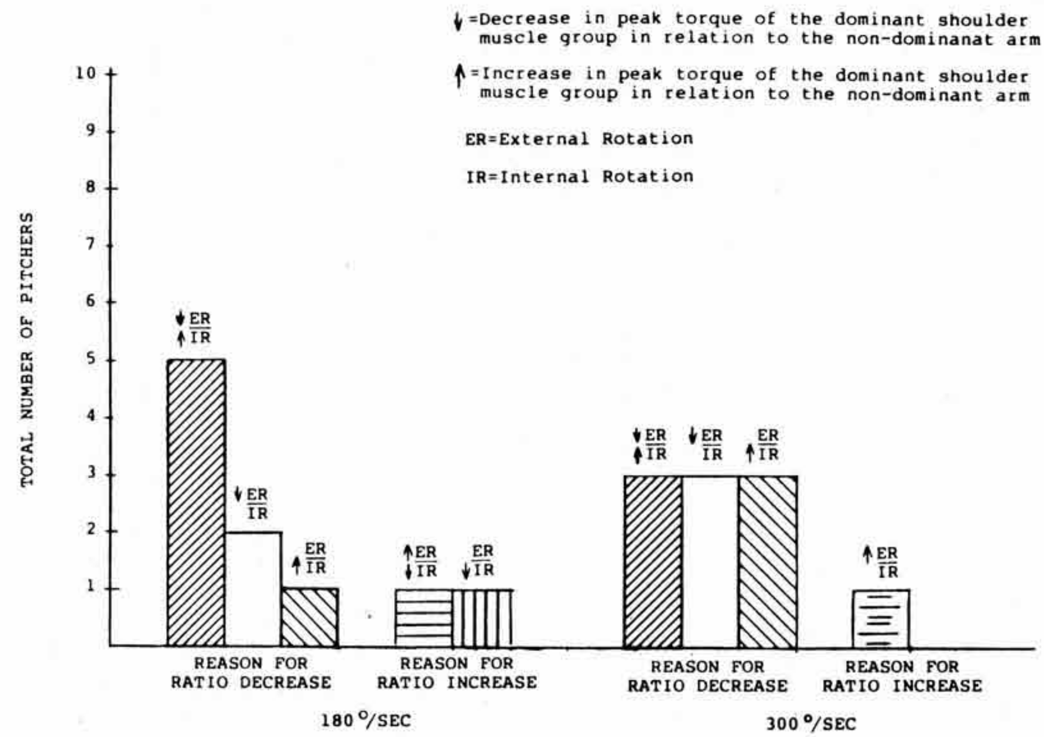

Fig. 4. *Graphic representation of factors influencing external/internal rotation ratio change about the shoulders of pitchers in their dominant arm in relation to their nondominant arm.*

motions which are not realistically duplicated by the Cybex. Straight plane motions of flexion/extension and internal/external rotation were selected for this experiment because they most closely approximate the pitching motion while maintaining appropriate stabilization of the body. However, Toyoshima et al.[21] have noted that pitching is a total body activity. Further, Pappas et al.[17] have described the anatomical sequence of throwing as proceeding from the fixed foot, up through the pelvis and trunk, to the upper extremity. Sequential rotations of each body segment generate torque which applies force to the ball. Therefore, the importance of the lower extremity and trunk should not be minimized.

As a procedure, the highest Cybex speed setting (300°/sec) was selected for this study because it has been documented that angular velocities of shoulder internal rotation during pitching may average 6000°/sec.[17] It was felt that muscle imbalances would be demonstrated more clearly at 300°/sec as pitchers are accustomed to moving at higher speeds. There was concern, however, that nonpitchers would be unable to perform adequately. As demonstrated by the results of this study, 300°/sec was too fast for either population. This supports the findings of Wallace et al.[24] who state that the best speed for testing normal shoulder flexion/extension is at slower speeds of approximately 120°/sec.

Both the pitchers and the nonpitchers had difficulty coordinating the change of direction, especially in the flexion/extension pattern. In addition, at higher speeds there appears to be a subconscious attempt to decelerate the arm near end range in anticipation of changing direction. This deceleration force was accomplished through eccentric contraction of antagonistic muscle groups.

Suggestions for Future Research

It is recommended that further study be directed toward the following topics: *1)* this experiment should be repeated using a larger random sample of both pitchers and nonpitchers to establish normative data, *2)* a follow-up study of the pitchers in this study to determine if those pitchers with greater muscle imbalance in their throwing arms developed a greater number of injuries than those pitchers with more balanced shoulder musculature, and *3)* a study placing a population of professional baseball pitchers on an eccentric strength training program for the shoulder external rotators to determine if this specific muscle

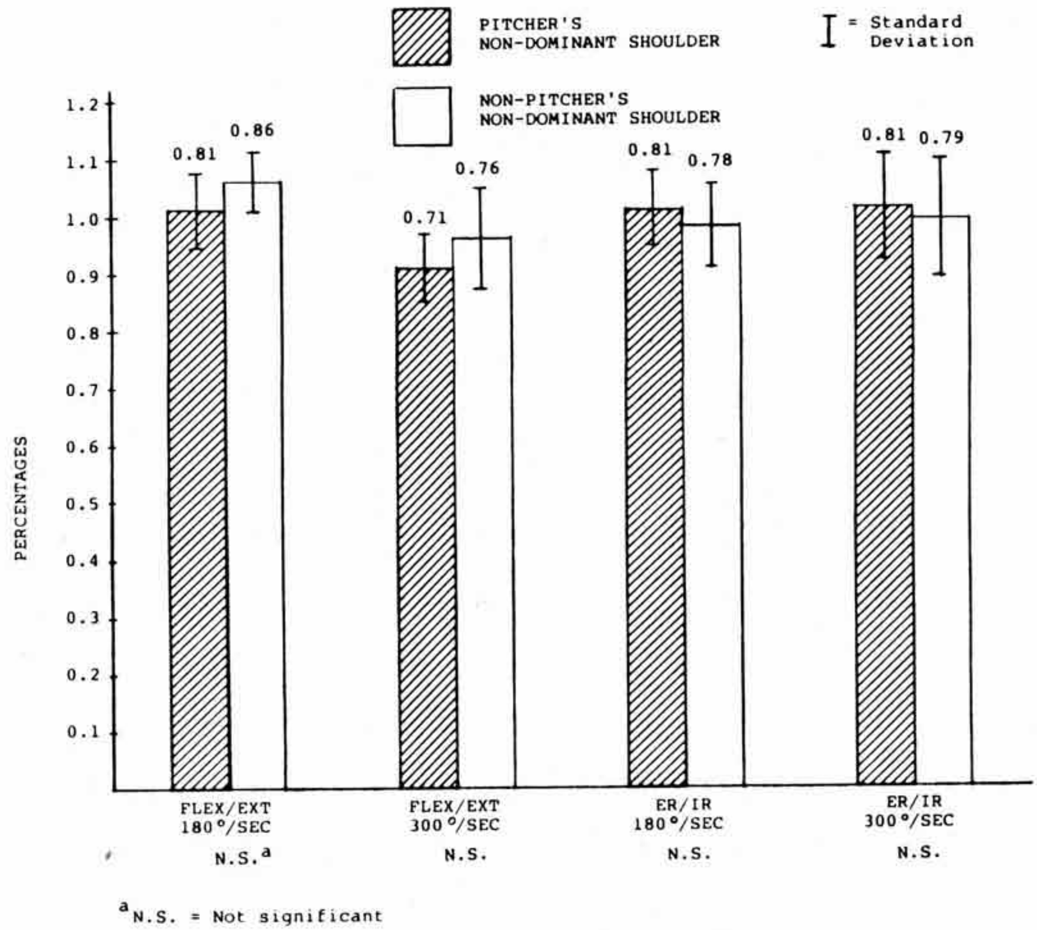

Fig. 5. *Shoulder strength ratios: comparison between pitchers' and nonpitchers' nondominant shoulders.*

training would decrease the incidence of shoulder injury during the following season.

Clinical Implications

Coplin[7] stated that the probability of muscle or joint injury increases if deviation from the naturally occurring muscle imbalances between antagonistic muscle groups are found. Therefore, if the act of pitching exacerbates an already apparent rotation imbalance in the shoulder, this could be a major cause of injury to a pitcher's throwing arm. Bateman[2] maintained that particular attention should be paid to the establishment and maintenance of sufficient external rotation strength to prevent shoulder injuries. These authors contend that the special population of pitchers must pay even greater attention to maintaining and/or increasing the strength of their external rotators in order to decrease their risk of shoulder injury. Because the external rotators appear to be used primarily as eccentric decelerators of the arm in pitching, perhaps strengthening programs should focus on eccentric training of the external rotators.

CONCLUSION

Results from this study indicate that *1)* there is a significant decrease in the shoulder strength ratio of external/internal rotation in a pitcher's throwing arm as compared with his nonthrowing arm, *2)* there is no significant difference between a pitcher's and nonpitcher's nondominant arms in both shoulder flexion/extension and shoulder external/internal rotation, and *3)* there is a significant difference between a pitcher and nonpitcher's dominant arms for both shoulder flexion/extension and external/internal rotation. These results imply that the act of pitching places unique stresses on a pitcher's throwing arm, especially on the external and internal rotators of the shoulder. Because of the special demands placed on a pitcher's throwing shoulder, pitchers, trainers, and clinicians should note that proper muscle balance and normal flexibility about the shoulder

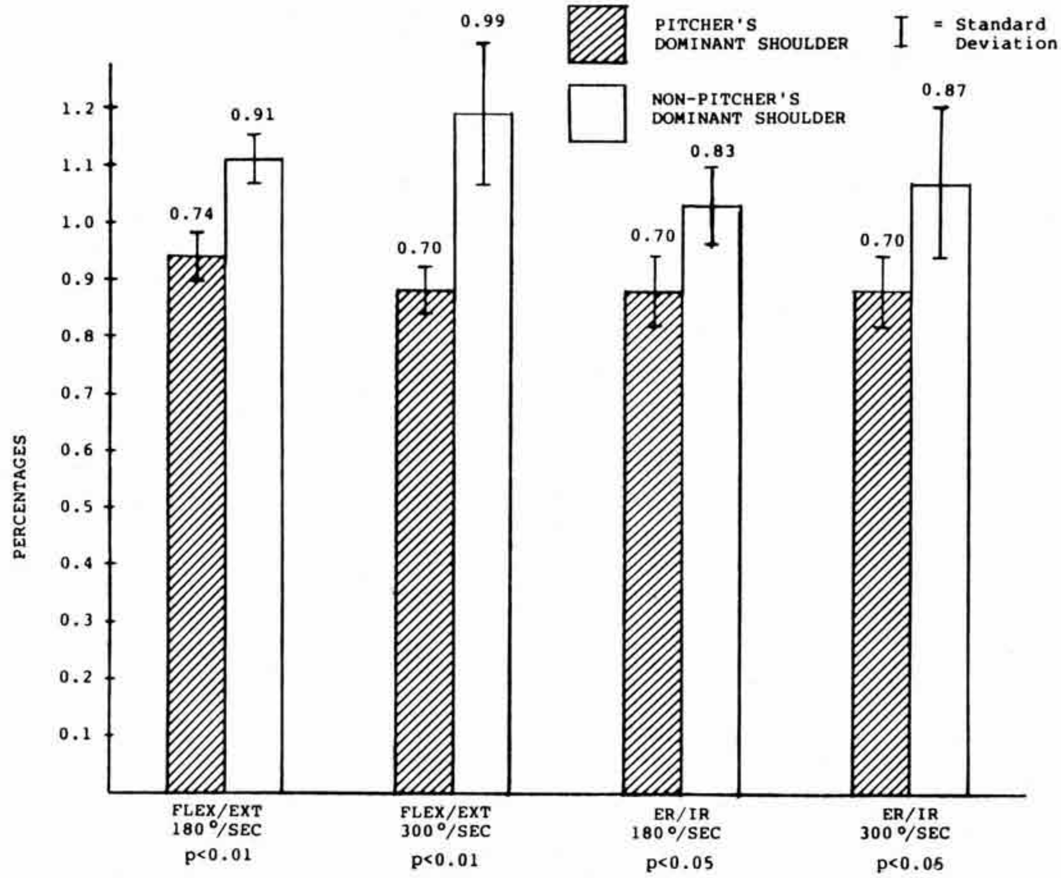

Fig. 6. *Shoulder strength ratios: comparison between pitchers' and nonpitchers' dominant shoulders.*

should be essential requirements for injury prevention. In particular, special attention should be placed on maintaining a proper muscle balance between the internal and external rotators of the shoulder.

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