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Kinematic and Kinetic Comparison Between Baseball Pitching and Football Passing

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Kinematic and kinetic aspects of baseball pitching and football passing were compared. Twenty-six high school and collegiate pitchers and 26 high school and collegiate quarterbacks were analyzed using three-dimensional high-speed motion analysis. Although maximum shoulder external rotation occurred earlier for quarterbacks, maximum angular velocity of pelvis rotation, upper torso rotation, elbow extension, and shoulder internal rotation occurred earlier and achieved greater magnitude for pitchers. Quarterbacks had shorter strides and stood more erect at ball release. During arm cocking, quarterbacks demonstrated greater elbow flexion and shoulder horizontal adduction. To decelerate the arm, pitchers generated greater compressive force at the elbow and greater compressive force and adduction torque at the shoulder. These results may help explain differences in performance and injury rates between the two sports.

Many talented athletes are both the quarterback on their school's football team and a pitcher on their baseball team. However, it is unknown whether participation in both activities is beneficial or detrimental to the athlete's performance and safety.

Theoretically, a football can be used as an overload weighted implement to strengthen the arm of a baseball pitcher, as it has been documented that overload training can increase the velocity of pitching regulation 0.14-kg (5-oz) baseballs. Brose and Hanson (1967) used college baseball players to study the effects that training with 0.28-kg (10-oz) overweight baseballs had on throwing velocity using regulation baseballs. They found a significant increase in throwing velocity subsequent to a 6-week overload training program. Litwhiler and Hamm (1973) included 5 college pitchers in a 12-week overload study using 0.20-kg (7-oz) to 0.34-kg (12-oz) baseballs and found that velocity for regulation baseballs increased an average of 5 m/s (11 mph) due to the 12-week training sessions. DeRenne, Buxton, Hetzler, and Ho (1994) studied the effects on throwing velocity of regulation baseballs due to training with underweight (0.11-kg) and overweight (0.17-kg) baseballs. In their study, a sample of 45 high school and 180 college baseball pitchers were randomly divided into three groups. Two groups used training programs that incorporated pitching underweight, overweight, and regulation baseballs, while the third

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group trained with regulation baseballs only (i.e., control group). After 10 weeks of training, the two experimental groups had significantly increased their velocity of pitching regulation baseballs, while the control group had no significant change. These studies indicate that training with slightly overweight baseballs can significantly increase the velocity of pitching regulation weight baseballs. A football, however, weighs three times as much as a baseball (0.42 kg vs. 0.14 kg), and no published study has examined the efficacy of training baseball pitchers with footballs. Nevertheless, some college and professional baseball coaches advise their pitchers to throw a football during the off-season (DeRenne & House, 1993).

Participation as both a pitcher and a quarterback may improve the athlete's performance on the football field as well. Because a baseball is lighter than a football, pitchers are believed to generate greater arm speed than quarterbacks. Thus, quarterbacks may be able to improve arm speed by training with baseball pitching. No study has examined the efficacy of underload weighted training for football quarterbacks.

In addition to enhancing performance, the throwing athlete is also interested in minimizing the risk of injury. By quantifying and comparing kinematic and kinetic aspects of these two throwing activities, previously proposed injury mechanisms can be evaluated. While several studies have documented kinematic and kinetic parameters during baseball pitching (Atwater, 1979; Campbell et al., 1994; Dillman, Fleisig, & Andrews, 1993; Elliott & Anderson, 1990; Elliott, Grove, Gibson, & Thurston, 1986; Feltner & Dapena, 1986; Fleisig, 1994; Fleisig, Dillman, Escamilla, & Andrews, 1995; Gainor, Piotrowski, Puhl, Allen, & Hagen, 1980; Horn, 1984; Pappas, Zawacki, & Sullivan, 1985; Sakurai, Ikegami, Okamoto, & Yabe, 1990; Sakurai, Ikegami, Okamoto, Yabe, & Toyoshima, 1993; Vaughn, 1985b; Werner, Fleisig, Dillman, & Andrews, 1993), minimal information about the kinematic and kinetic aspects of football passing is available (Rash & Shapiro, 1995), and no study has compared the biomechanics of the two throws. The purpose of this study was to compare kinematic and kinetic parameters of baseball pitching to football passing; results were evaluated relative to potential benefits and detriments of participation in both activities.

Methods

Twenty-six quarterbacks (13 collegiate, 13 high school) and 26 baseball pitchers (13 collegiate, 13 high school) were subjects for this study. All 52 athletes were healthy males who were active on their schools' teams at the time of testing. Mean height was 1.84 ± 0.06 m for the quarterbacks and 1.84 ± 0.07 m for the pitchers. The quarterbacks had a mean mass of 82.0 ± 8.3 kg and the pitchers had a mean mass of 80.2 ± 10.5 kg.

After completing informed consent and history forms, each subject was tested with a procedure previously described (Dillman et al., 1993; Fleisig, 1994; Fleisig et al., 1995). With this procedure reflective markers were attached bilaterally to the distal end of the midtoe, lateral malleolus, lateral femoral epicondyle, greater trochanter, lateral tip of the acromion, and lateral humeral epicondyle. A reflective band was wrapped around the wrist on the throwing arm, and a reflective marker was attached to the ulnar styloid of the nonthrowing arm. After stretching and warming up, the subject threw 10 balls in an indoor laboratory for data collection. Baseball pitchers threw from a portable pitching mound (Athletic Training Equipment Company, Santa Cruz, CA) toward a strike-zone ribbon located over a home plate at a distance of 18.4 m (60.5 ft) from the pitching rubber (Figure 1). Football quarterbacks threw dropback passes from flat ground toward a target net located approximately 18.4 m from their location at the time of ball release (Figure 2).

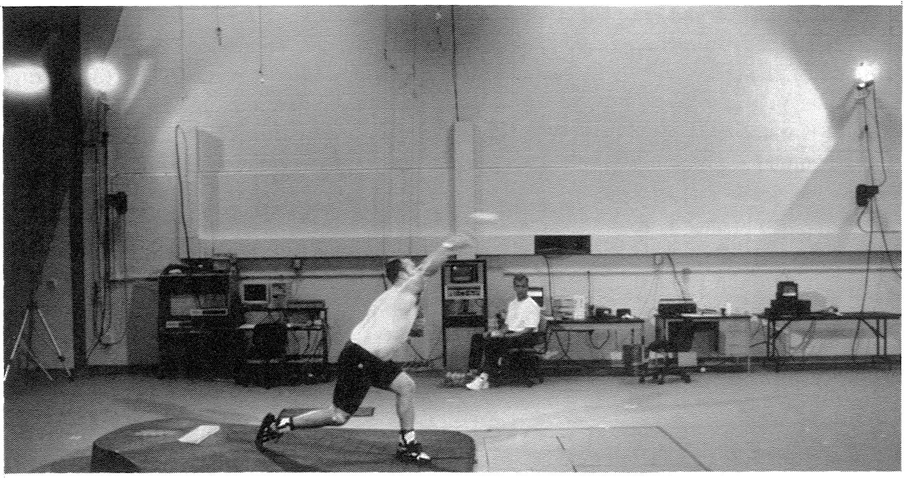

Figure 1 — A baseball pitcher during testing.

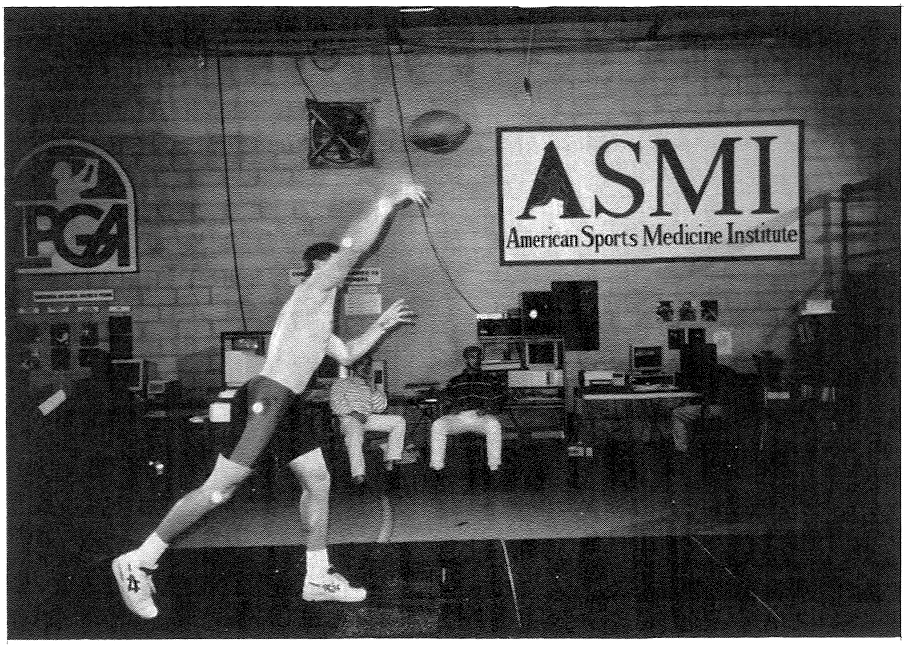

Figure 2 — A football quarterback during testing.

Ball velocity was recorded with a Tribar Sport radar gun (Jugs Pitching Machine Company, Tualatin, OR) as the ball left the athlete's hand.

A three-dimensional automatic digitizing system (Motion Analysis Corporation, Santa Rosa, CA) was used to quantify each athlete's motion. Four electronically synchronized 200-Hz charged coupled device (CCD) cameras transmitted pixel images of the reflective markers directly into a video processor without being recorded onto video. Three-dimensional marker locations were calculated with Motion Analysis Corporation Expertvision 3-D software utilizing the direct linear transformation (DLT) method (Abdel-Aziz & Karara, 1971; Shapiro, 1978; Walton, 1981).

Camera coefficients were calibrated by recording the position of markers attached to four vertically suspended wires. Three reflective markers spaced at 61-cm intervals were attached to each wire. The wires were positioned so that the markers made a matrix approximately 1.5 m × 1.2 m × 1.2 m in size, suspended approximately 0.3 m above the ground, where the 1.5 m dimension was aligned with the direction of throwing. This matrix was designed to encompass as much of the testing area as possible while leaving each marker within the field of view of all four cameras. In general, the foot and ankle markers were the only markers that did not stay within the calibrated space, which was reasonable considering that the subjects had a mean height of 1.84 m and the pitchers had a mean stride length of 1.36 m. The root mean-square error in calculating the three-dimensional location of markers randomly placed within the calibrated space was 1.0 cm (Fleisig et al., 1995).

Positional data were digitally filtered independently in the X, Y, and Z directions with a Butterworth low-pass filter (Winter, 1990). Qualitative evaluation of displacement, velocity, and acceleration data indicated that a (sample frequency)/(cut-off frequency) ratio of 12 was effective at rejecting noise and passing data. For a 200-Hz sample frequency, this was equivalent to a second-order, low-pass, cutoff frequency of 16.7 Hz (200 Hz/16.7 Hz = 12). As suggested by Winter, Sidwall, and Hobson (1974), the data were passed through the filter a second time, in the reverse order, to eliminate phase distortion. In effect, this second passing created a fourth-order, zero-phase-shift, low-pass filter. By passing the data through the filter a second time, the cutoff frequency was reduced by 0.802; thus, the cutoff frequency for this double-pass filter was 13.4 Hz (16.7 Hz × 0.802).

The locations of the midhip, midshoulder, elbow joint center, and shoulder joint center, shown in Figure 3, were calculated in each frame as described by Dillman et al. (1993). Midhip was the midpoint of a line segment between the two hip markers, and midshoulder was the midpoint of a line segment between the two shoulder markers. Shoulder and elbow locations were translated from surface markers to estimated joint centers (see the appendix). Although these joint centers were simply estimations, they were better representatives of joint location than were the surface markers.

In each time frame, trunk, pelvis, and upper torso unit vectors were calculated. The trunk vector was a unit vector from the midhip to the midshoulder; the pelvis vector was a unit vector from the lead hip to the throwing hip; and the upper torso vector was a unit vector from the lead shoulder to the midshoulder. In each time frame, local reference frames were calculated at the shoulder (R_s), the elbow (R_e), and the trunk (R_t) (Figure 3). The unit vectors included in these reference frames, described in Table 1, were calculated as follows: Z_s was a vector from the throwing shoulder joint center to the throwing elbow joint center, Z_e was a vector from the throwing elbow joint center to the throwing wrist, Z_t was a vector from the leading shoulder to the midshoulder, X_s was the cross-product of the trunk vector and Z_s, Y_s was the cross-product of Z_s and X_s, X_e was the cross-product of Z_e and Z_s, Y_e was the cross-product of Z_e and X_e, X_t was the cross-product of the trunk vector and Z_t, and Y_t was the cross-product of Z_t and X_t. All reference frame vectors were normalized to unit length.

Angular displacement and velocity of the shoulder and elbow were calculated as previously described (Dillman et al., 1993). Abduction was the angle between the distal direction of the upper arm and the inferior direction of the trunk in the frontal (Y_tZ_t) plane

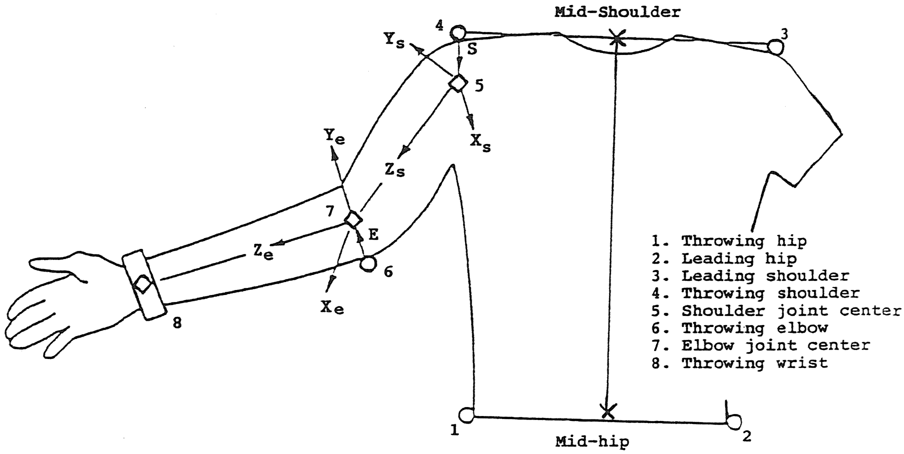

Figure 3 — Reflective markers (O) and calculated targets (◊ and ×). Translation vectors (S and E) and local reference frames for the shoulder (R_s) and elbow (R_e) also shown. Adapted from Dillman et al. (1993).

Table 1 Local Reference Frames

	Unit vector	Description
Shoulder reference frame (R_s)	X_s	Anterior direction of shoulder
	Y_s	Superior direction of shoulder
	Z_s	Distal direction of upper arm
Elbow reference frame (R_e)	X_e	Medial direction of elbow
	Y_e	Anterior direction of elbow
	Z_e	Distal direction of forearm
Trunk reference frame (R_t)	X_t	Anterior direction of trunk
	Y_t	Superior direction of trunk
	Z_t	Lateral direction of trunk

(Figure 4a). Horizontal adduction was defined as the angle between the distal direction of the upper arm and the upper torso vector in the transverse (X_tZ_t) plane (Figure 4b). Since external rotation of the humerus about its long axis could not be directly measured, the rotation of the forearm about the upper arm's long axis was used, as previously described by Vaughn (1985a) and Feltner and Dapena (1986). Using this method, we calculated external rotation as the angle between the trunk's anterior direction and the forearm's distal direction, in a plane perpendicular to the upper arm (X_sY_s plane) (Figure 4c). Elbow flexion of the throwing arm was defined as the angle between the distal directions of the upper arm and forearm (Figure 4d).

Knee flexion of the lead leg was defined as the angle between the distal directions of the upper and lower leg (Figure 4e). Trunk tilt forward was the angle between the

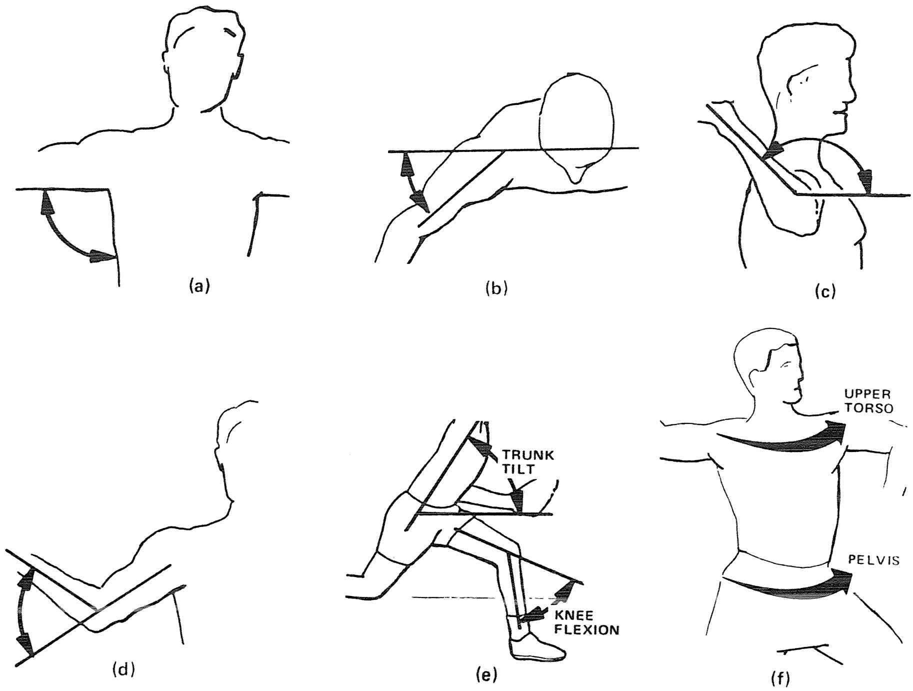

Figure 4 — Definition of kinematic variables: (a) shoulder abduction, (b) horizontal adduction, (c) external rotation, (d) elbow flexion, (e) lead knee flexion and trunk tilt, and (f) pelvis angular velocity and upper torso angular velocity.

superior direction of the trunk and the global X direction (i.e., toward the thrower's target) in the global XZ plane (Figure 4e). Trunk tilt forward was therefore 0° when the trunk was horizontal toward the target and 90° when the trunk was vertical. For each angular displacement measurement, the corresponding velocity was calculated using the 5-point central difference method (Miller & Nelson, 1973).

Angular velocities of the pelvis and upper torso (Figure 4f) were calculated with a method published by Feltner and Dapena (1989). Angular velocity of the pelvis was the cross-product of the pelvis vector and its derivative. Angular velocity of the upper torso was the cross-product of the upper torso vector and its derivative.

Forces produced at the elbow and shoulder joints were calculated with a previously described procedure (Feltner & Dapena, 1989; Fleisig, 1994). This procedure utilized Newton's second law of motion; specifically, the sum of all forces applied to each segment of the upper extremity was set equal to the mass of that segment multiplied by the linear acceleration of its center of mass. The positions of center of mass of the forearm and upper arm were determined using Clauser, McConville, and Young's (1969) cadaveric data. Due to limitations in camera resolution, markers could not be placed on the hand, and the mass of the hand was therefore assumed to be at the wrist marker. The five-point central difference method for second derivatives was used to determine the linear acceleration of each segment's center of mass (Miller & Nelson, 1973). The masses of a baseball and football were set equal to 0.14 kg and 0.43 kg, respectively. The mass of each upper extremity segment was assumed to be a percentage of the subject's total mass (Clauser et al., 1969).

Following a procedure first described by Feltner and Dapena (1989) and later used by Fleisig (1994), the sum of all torques applied to each segment was set equal to the vector product of the segment's moment of inertia and angular acceleration. Moments of inertia of the hand and ball were assumed to be negligible. Moments of inertia of the forearm and upper arm were determined from Dempster's (1955) cadaveric study. Moment of inertia values were then individualized using each subject's height and mass and a procedure developed by Dapena (1978). Angular velocity of the forearm or upper arm about the transverse axis was the cross-product of a unit vector aligned in the distal direction of the segment and the derivative of this vector (Feltner & Dapena, 1989). Feltner and Dapena (1989) neglected the angular velocity about the longitudinal axis for both the forearm and upper arm. Although the angular velocity about the longitudinal axis is small for forearm supination/pronation (Feltner & Dapena, 1986; Sakurai et al., 1993), it is substantial for upper arm internal rotation (Dillman et al., 1993; Feltner & Dapena, 1986; Pappas et al., 1985). Hence, angular velocity about the longitudinal axis was assumed to be zero for the forearm but was equated to the derivative of external/internal rotation for the upper arm.

Kinetic values were reported as the force and torque applied by the upper arm to the forearm about the elbow and as the force and torque applied by the trunk to the upper arm at the shoulder (Fleisig et al., 1995). Kinetic values were separated into orthogonal components using the axes shown in Table 1 and Figure 3. Shoulder force was separated into three components (Figure 5a): anterior ($+X_s$) and posterior ($-X_s$), superior ($+Y_s$) and inferior ($-Y_s$), and distractive ($+Z_s$) and compressive ($-Z_s$). Shoulder torque was separated into three components (Figure 5b): adduction ($+X_s$) and abduction ($-X_s$), horizontal adduction ($+Y_s$) and horizontal abduction ($-Y_s$), and external rotation ($+Z_s$) and internal rotation ($-Z_s$). Elbow force was separated into three components (Figure 5c): medial ($+X_e$) and lateral ($-X_e$) force, anterior ($+Y_e$) and posterior ($-Y_e$) force, and distractive ($+Z_e$) and compressive ($-Z_e$) force. Elbow torque was separated into two components (Figure 5d): extension ($+X_e$) and flexion ($-X_e$) torque, and varus ($+Y_e$) and valgus ($-Y_e$) torque. Supination ($+Z_e$) and pronation ($-Z_e$) torque at the elbow could not be calculated with the model used; however, Feltner and Dapena (1986) showed that these torques were fairly minimal.

To eliminate any effects of variation in body size, kinetic data were normalized as follows: Forces for each athlete were divided by his body weight and multiplied by the average subject body weight (795 N); torques for each athlete were divided by both his body weight and his height and multiplied by the average subject body weight and the average subject height (1.84 m). Temporal data were reported as percentages of the throw completed, where 0% corresponded to the instant when the front foot contacted the ground and 100% was the instant of ball release.

For each subject, data for the three fastest throws that struck the baseball strike zone or football target net were averaged. Differences between baseball pitching and football passing were statistically tested with Student's t test. The significance level for this analysis was set at $p < .01$.

To simplify interpretation of results, the throwing motion was divided into six phases previously defined for baseball pitching (Dillman et al., 1993; Werner et al., 1993): windup, stride, arm cocking, arm acceleration, arm deceleration, and follow-through (Figure 6). The windup phase began when the thrower initiated his first movement and ended when the lead leg was lifted and the two hands were separated. Next was the stride phase, which ended when the front foot contacted the ground. The arm cocking phase followed, ending when the throwing shoulder reached maximum external rotation. Subsequently the arm acceleration phase occurred, which ended at ball release. The time from ball release until the shoulder reached maximum internal rotation was defined as the arm deceleration phase.

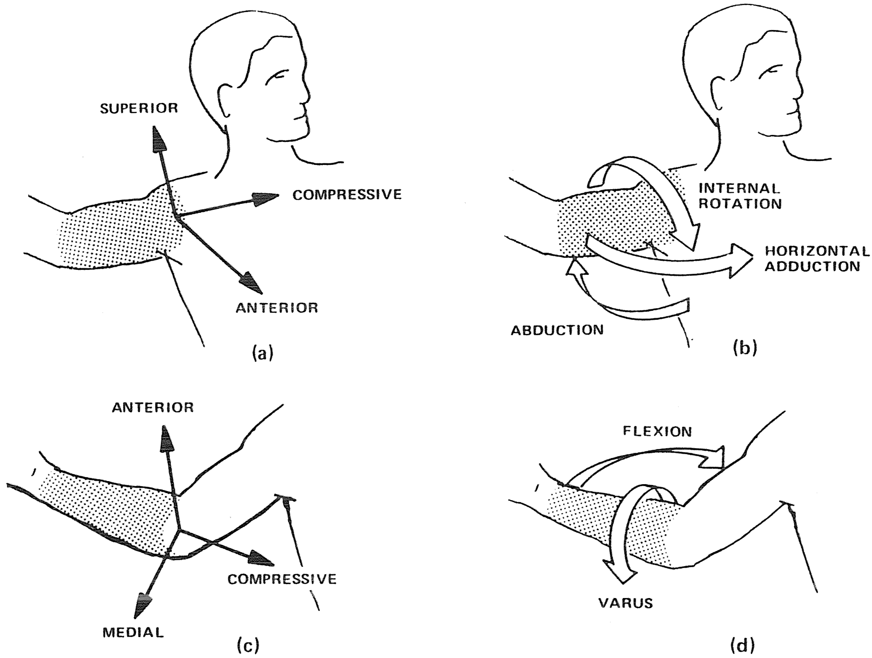

Figure 5 — Definition of kinetic variables: (a) shoulder forces, (b) shoulder torques, (c) elbow forces, and (d) elbow torques.

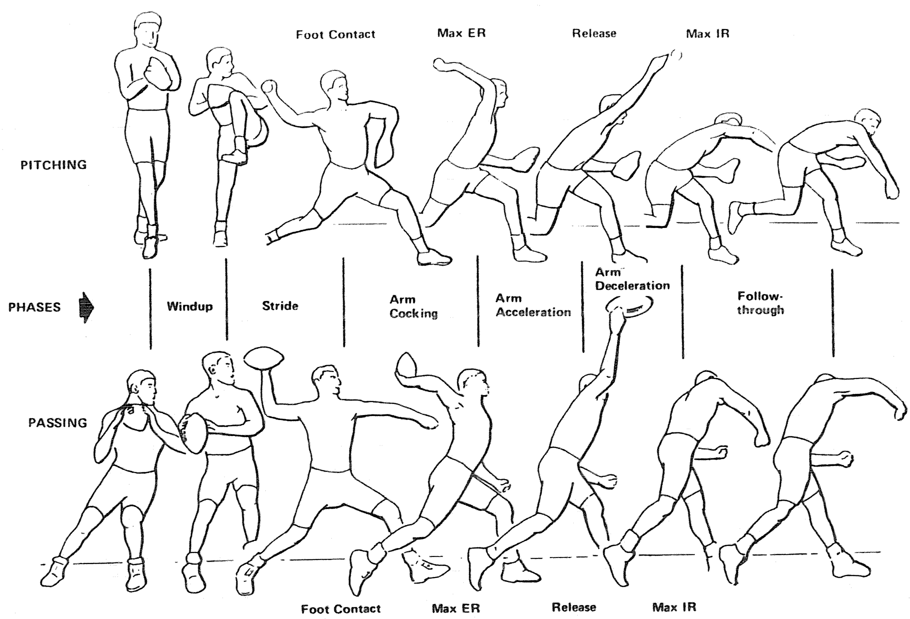

Figure 6 — The six phases of throwing.

The final phase was follow-through, which started at the time of maximum shoulder internal rotation and ended when the athlete had reached his balanced position to continue playing. Data were analyzed for the arm cocking, arm acceleration, arm deceleration, and follow-through phases, as previous studies have shown that the largest magnitudes of angular displacement, angular velocity, joint force, and joint torque occur during these phases (Dillman et al., 1993; Elliott et al., 1986; Feltner & Dapena, 1986; Fleisig et al., 1995; Pappas et al., 1985; Sakurai et al., 1990; Sakurai et al., 1993; Vaughn, 1985b; Werner et al., 1993).

Results

Although pitchers and quarterbacks displayed a similar throwing motion, several kinematic differences were quantified (Table 2). Among the statistically significant differences were that pitchers achieved not only greater ball velocity but also greater rotational speeds of the arm (i.e., elbow extension and internal rotation angular velocity) and trunk (i.e., pelvis and upper torso angular velocity). Although quarterbacks had greater shoulder external rotation than pitchers at the instant of foot contact, pitchers demonstrated greater maximum shoulder external rotation during the arm cocking phase. At the instant of ball release, quarterbacks stood more erect—based upon trunk tilt forward and lead knee flexion—and had shorter strides than pitchers. In addition, quarterbacks tended to "lead with the elbow" more than pitchers, displaying greater shoulder horizontal adduction and elbow flexion during arm cocking and at the instant of ball release. During the arm deceleration phase, greater upper torso angular velocity was seen for pitchers.

Timing of kinematic measurements is compared between baseball pitching and football passing in Table 3. Pitchers achieved maximum angular velocity of the pelvis and upper torso earlier (relative to foot contact) than quarterbacks did. Although quarterbacks externally rotated their shoulder earlier, pitchers achieved maximum angular velocity (elbow extension and shoulder internal rotation) of the throwing arm sooner. A comparison of kinetic data between baseball pitching and football passing is presented in Table 4. Pitchers generated greater compressive force at the elbow and greater compressive force and adduction torque at the shoulder to decelerate the rapidly moving throwing arm.

Discussion

Although pitching biomechanics have been studied by numerous researchers, football passing biomechanics have been previously investigated only by Rash and Shapiro (1995). Because football passing biomechanics are not well documented, a comparison of our results to the data presented by Rash and Shapiro is worthwhile. In the present study 26 high school and college quarterbacks were used, whereas 12 college quarterbacks were studied by Rash and Shapiro (1995). Even though high school athletes were utilized in the present study, ball speeds (21 ± 2 m/s) were higher than those reported by Rash and Shapiro (18 ± 3 m/s). In the present study, quarterbacks had 108 ± 8° of shoulder abduction during the arm acceleration phase and 26 ± 9° of shoulder horizontal adduction at the instant of ball release, whereas Rash and Shapiro reported 96 ± 6° of abduction and 12 ± 9° of horizontal adduction at ball release. Maximum angular velocities of the throwing arm were substantially higher in the present study (elbow extension = 1,760 ± 210°/s; internal rotation = 4,950 ± 1,080°/s) compared to the data reported by Rash and Shapiro (elbow extension = 1,280 ± 209°/s; internal rotation = 2,990 ± 1,040°/s). Kinetic values also were substantially greater than those previously reported by Rash and Shapiro; for example, the current study showed greater elbow varus torque (54 N · m vs. 19 N · m), shoulder compressive force (660 N vs. 435 N), and elbow compressive force (620 N vs. 345 N).

Table 2 Kinematic Comparison Between Baseball Pitching and Football Passing

Parameter	Pitching (n = 26) Mean	Pitching (n = 26) *SD*	Passing (n = 26) Mean	Passing (n = 26) *SD*
Instant of foot contact				
Stride length from ankle to ankle (% height)**	74	5	61	8
Shoulder abduction (°)	93	12	96	13
Shoulder horizontal adduction (°)**	–17	12	7	15
Shoulder external rotation (°)*	67	24	90	33
Elbow flexion (°)**	98	18	77	12
Lead knee flexion (°)**	51	11	39	11
Arm cocking phase				
Maximum pelvis angular velocity (°/s)**	660	80	500	110
Maximum shoulder horizontal adduction (°)**	18	8	32	9
Maximum upper torso angular velocity (°/s)**	1,170	100	950	130
Maximum elbow flexion (°)**	100	13	113	10
Instant of maximum shoulder external rotation				
Maximum shoulder external rotation (°)*	173	10	164	12
Arm acceleration phase				
Maximum elbow extension velocity (°/s)**	2,340	300	1,760	210
Average shoulder abduction during acceleration (°)**	93	9	108	8
Instant of ball release				
Ball velocity (m/s)**	35	3	21	2
Shoulder horizontal adduction (°)**	7	7	26	9
Elbow flexion (°)**	22	6	36	8
Trunk tilt forward (°)*	58	10	65	8
Trunk tilt sideways (°)**	124	9	116	5
Lead knee flexion (°)**	40	12	28	9
Arm deceleration phase				
Maximum shoulder internal rotation velocity (°/s)**	7,550	1,360	4,950	1,080
Minimum elbow flexion (°)**	18	5	24	5
Average upper torso angular velocity (°/s)**	470	160	310	110

$^{*}p < .01$. $^{**}p < .001$.

One possible explanation for the considerable discrepancies between the two studies was the difference in data sampling rates; data were collected at 200 Hz in the current study and at 60 Hz in the study by Rash and Shapiro. Although 60-Hz cameras are sufficient for displacement measurements and leg and trunk motions, their adequacy for quantifying the high-speed motion of the throwing arm should be justified. To investigate this issue, we reevaluated three randomly selected football passing trials from the current study utilizing only every third sample of camera data (i.e., [200 Hz]/3 = 67 Hz). These lower frequency data were filtered with a 13.4-Hz, fourth-order, zero-phase-shift Butterworth low-pass filter and reevaluated with the analysis methods described above. Table 5 shows

Table 3 Timing of Kinematic Measurements, Compared Between Baseball Pitching and Football Passing

Parameter	Pitching (n = 26) Mean	*SD*	Passing (n = 26) Mean	*SD*
Instant of foot contact	0	0	0	0
Arm cocking phase				
Maximum pelvis angular velocity**	35	19	56	12
Maximum shoulder horizontal adduction	49	17	55	21
Maximum upper torso angular velocity**	50	8	62	10
Maximum elbow flexion	53	14	53	11
*Instant of maximum shoulder external rotation**	81	4	71	14
Arm acceleration phase				
Maximum elbow extension velocity**	92	3	95	2
Maximum trunk-tilt angular velocity**	99	16	76	14
Instant of ball release	100	0	100	0
Arm deceleration phase				
Maximum shoulder internal rotation velocity**	103	2	106	2
Minimum elbow flexion (°)**	103	2	107	3

Note. Each number in the table represents a percentage of throw completed, where 0% was defined as the instant of foot contact, and 100% was the instant of ball release. Length of time for 100% of a throw was significantly different ($p < .001$) between pitching (0.145 ± 0.022 s) and passing (0.207 ± 0.037 s).

*$p < .01$. **$p < .001$.

that when the three throws were analyzed with 67-Hz data, shoulder internal rotation velocities were reduced approximately 25% (in comparison, Rash's values were 50% lower than those in the present study) while other movements were not noticeably affected. Hence, sampling rate may partially explain differences in kinematic and kinetic values. Other possible factors include skill level, ball velocity, and methodological errors (such as inaccuracy in calculating shoulder internal rotation position and velocity when the elbow is near full extension). Since the methods used in the present study were similar for baseball pitching and football passing, a statistical comparison among the subjects tested in this study is reasonable.

Because the football had more mass than the baseball, quarterbacks could not generate as much shoulder internal rotation velocity as pitchers did. To compensate, quarterbacks rotated their shoulders sooner and achieved maximum external rotation earlier in the throw than the pitchers, thereby allowing more time for acceleration of internal rotation. Throwing the heavier football also seemed to correlate with two other mechanical adjustments: "leading with the elbow" and decreased contribution from the trunk and legs. Leading with the elbow—that is, using increased shoulder horizontal adduction and elbow flexion—was observed for quarterbacks. The decreased contribution from the trunk and legs was seen as a shorter stride, more upright trunk, and reduced pelvis and upper

Table 4 Kinetic Comparison Between Baseball Pitching and Football Passing

Parameter	Pitching (n = 26) Mean	Pitching SD	Passing (n = 26) Mean	Passing SD
Arm cocking phase				
Maximum shoulder anterior force	310	50	350	80
Maximum shoulder horizontal adduction torque	82	13	78	19
Maximum shoulder internal rotational torque	54	10	54	13
Maximum elbow medial force	260	50	280	60
Maximum elbow varus torque	51	10	54	13
Arm acceleration phase				
Maximum elbow flexion torque	47	9	41	8
Arm deceleration phase				
Maximum shoulder compressive force*	850	140	660	120
Maximum elbow compressive force**	710	110	620	110
Maximum shoulder adduction torque*	79	23	58	34
Follow-through phase				
Maximum shoulder posterior force	310	110	240	120
Maximum shoulder horizontal abduction torque	85	51	80	34

Note. Elbow kinetic data are presented as forces and torques applied by the arm onto the forearm. Shoulder kinetic data are presented as forces and torques applied by the trunk onto the arm. Forces were normalized by body weight and are expressed in newtons. Torques were normalized by body weight and height and are expressed in newton-meters.

*$p < .01$. **$p < .001$.

torso angular velocity. At release, during arm deceleration, and during follow-through, pitchers had more trunk tilt and knee flexion than quarterbacks. Furthermore, pitchers had greater rotation of the upper torso after release, based upon greater upper torso angular velocity during the arm deceleration phase. A complete follow-through motion was critical for pitchers to decelerate the rapidly moving arm. Even with a complete follow-through, forces and torques generated at the elbow and shoulder to decelerate the arm were greater in pitchers than in quarterbacks. Although a full follow-through might be advantageous for quarterbacks as well, it is impractical as a quarterback must quickly regain a balanced position after throwing the ball and prepare for possible impact from an opposing player.

Throwing injuries associated with baseball pitching are well documented (Andrews, 1985a, 1985b, 1993; Andrews, Kupferman, & Dillman, 1991; Andrews, McCluskey, & McLeod, 1976; Branch, Partin, Chamberland, Emeterio, & Sabetelle, 1992; Chandler, 1992; DeHaven, 1973; Grana & Rashkin, 1980; Jobe & Kvitne, 1989; Lipscomb, 1975; Pappas & Zawacki, 1991; Stacey, 1984; Sterling, Calvo, & Holden, 1991). The rate of throwing injuries is assumed to be less in football, as no studies have reported injuries resulting from football throwing. A comparison of pitching and passing data from the present study with respect to injury mechanisms may add insight about the apparent disparity in injury risk between the two types of throws.

Table 5 Calculated Velocities and Kinetic Values for Different Sample Rates for Three Randomly Selected College Football Trials

Parameter	Trial ID	Calculated results (200 Hz data)	(67 Hz data)
Maximum elbow extension velocity (°/s)	fk115005	1,250	1,165
	sw109504	1,660	1,600
	tw96207	2,060	2,030
Maximum shoulder internal rotation velocity (°/s)	fk115005	3,500	2,870
	sw109504	4,390	3,435
	tw96207	5,920	4,280
Maximum elbow varus torque (N · m)	fk115005	49	49
	sw109504	46	44
	tw96207	59	59
Maximum shoulder compressive force (N)	fk115005	570	590
	sw109504	770	740
	tw96207	870	860
Maximum elbow compressive force (N)	fk115005	490	480
	sw109504	650	650
	tw96207	790	770

Throwing injuries may occur at the medial, lateral, or posteromedial aspect of the elbow (Atwater, 1979). To prevent such injuries and maintain joint stability, a varus torque must be applied at the elbow (Fleisig et al., 1995). Based upon in vitro research by Morrey and An (1983), approximately 54% of this torque is provided by soft tissue (e.g., tension in the ulnar collateral ligament) and 33% is provided by bony articulation (e.g., compression between the radial head and capitellum). No significant difference in magnitude of varus torque was seen, providing no help in explaining differences in medial and lateral elbow injury rates between the two sports. Perhaps some other factor such as increased elbow flexion in football passing may be related to the low rate of injuries observed in this activity. Posteromedial elbow injury, specifically impingement of the olecranon in the olecranon fossa, is caused by the combination of elbow varus torque and elbow extension (Fleisig et al., 1995). Greater elbow extension velocity and elbow extension (i.e., decreased elbow flexion during the arm deceleration phase) in baseball pitching may be related to the higher injury frequency observed in this throw.

McLeod and Andrews (1986) stated that pitching injuries to the anterior glenoid labrum of the shoulder can be caused by any force that shifts the humerus to the rim of the glenoid fossa. During the arm cocking phase, no significant difference in shoulder anterior force was seen between quarterbacks and pitchers. One possible explanation for the lower incidence of anterior labrum injuries for quarterbacks is greater glenohumeral joint stability due to greater horizontal adduction. Andrews and Angelo (1988) found that most rotator cuff injuries in throwers were located between the posterior midsupraspinatus and the midinfraspinatus, which they believed resulted from distraction, horizontal adduction, and internal rotation at the shoulder during arm deceleration. The greater shoulder compressive force to resist distraction and greater shoulder internal rotation velocity for baseball pitching may be related to the greater risk of rotator cuff injury. Subacromial impingement is another pathology common in the throwing shoulder. As the shoulder is abducted and externally rotated, the rotator cuff, biceps tendon, or subacromial bursa may become impinged under the coracoacromial arch (Atwater, 1979; Chandler, 1992; Fleisig et al., 1995). Although shoulder abduction during the arm acceleration phase was significantly greater in football passing, the greater shoulder external rotation during arm cocking measured in baseball pitching may be related to the high risk of impingement for pitchers.

In addition to fitting the constraints of the game, trunk kinematic parameters of football quarterbacks may also be related to limiting the risk of arm injury. The kinetic chain principle asserts that in a coordinated human motion, energy or momentum is transferred through sequential body segments, achieving maximum magnitude in the terminal segment (Kreighbaum & Barthels, 1990; Norkin & Levangie, 1983; Steindler, 1955). By limiting leg motion, pelvis rotation, and upper torso rotation, quarterbacks may be regulating the momentum or energy transferred to the throwing arm and limiting the force and torque produced at the shoulder and elbow joints.

These mechanical considerations are, of course, only some of the elements possibly related to injury. Other factors such as number of hard throws, rest between performances, warm-up routine, conditioning program, and anatomical variations must also be considered. For instance, a starting pitcher may throw 120 pitches in a game every fifth day, whereas a quarterback might throw 50 passes in a game every seventh day. The increased number of throws seen in baseball might lead to fatigue and instability in the pitcher's arm, exacerbating injury potential late in the game.

Conclusions

One objective of the current study was to determine whether higher forces are generated in football passing than in baseball pitching, as it has been proposed that football passing could be used to strengthen a baseball pitcher's arm. Football passing did not produce greater forces or torques. In fact, during the arm deceleration phase greater forces and torques in the shoulder and elbow were produced by pitchers; this may be related to the increased incidence of injury from repetitive throwing that occurs in pitching. Computer simulation of joint components may be helpful in estimating the distribution of loads among the hard and soft tissues of the joints.

Another objective was to determine whether pitchers generate greater arm velocity than quarterbacks, as quarterbacks might use baseball pitching to develop arm speed. Higher arm speeds were indeed generated in pitching; however, baseball pitching might be detrimental for quarterbacks since they might learn inappropriate throwing mechanics. Furthermore, the greater incidence of overuse injury in pitching indicates that pitching may unnecessarily increase a quarterback's risk of arm injury.

In summary, the two throws are similar but not identical. Although the throws were qualitatively similar during the arm cocking, arm acceleration, and arm deceleration phases, quantifiable kinematic, kinetic, and timing differences were found. Although research is certainly needed to clinically measure the training effects of throwing both baseballs and footballs, our recommendation is that a baseball pitcher or football quarterback should not use the other throw during the competitive season, as improper mechanics may develop. Training with the other throw during the off-season, however, may be beneficial. This could be true especially for the adolescent or prepubescent athlete, whose objective should be to develop general fitness and athletic skills without committing to the specialization of one sport.

With the dearth of information concerning the cross-training effects of baseball pitching and football passing, caution should be taken. Participation in both sports may have deleterious effects, as differences between pitching and passing may lead to improper throwing mechanics in either sport. Also, differences in shoulder and elbow kinetic parameters between the two throwing patterns may affect the potential for arm injury. It is imperative for any athlete who throws both footballs and baseballs to use a year-round conditioning program that recognizes the demands of both activities.

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Appendix: Calculation of Elbow and Shoulder Joint Centers

A method was developed for determining elbow and shoulder joint center locations based upon the locations of surface markers (Fleisig, 1994). First, the locations of the joint centers and surface markers were manually digitized for a small sample of subjects. Local reference frames for the trunk and elbow were then established using the surface markers. Next, the locations of the shoulder and elbow joint centers were expressed as functions of the local reference frames and the length of a subject's humerus and radius. The development of the general equations is presented below, followed by application of the equations for each athlete.

General Equations

Pitching mechanics of four subjects were recorded at 500 Hz onto videotape with two synchronized EktaPro 1000 cameras (Motion Analysis Systems Division, Eastman Kodak Company, San Diego, CA). Reflective markers (placed as described in the Methods section) and the elbow and shoulder joint centers of the throwing arm were manually digitized with a Peak 3D Motion Measurement System (Peak Performance Technologies, Englewood, CO). In each frame, midhip was the midpoint of a line segment between the two hip markers, and midshoulder was the midpoint of a line segment between the two shoulder markers. Trunk, shoulder, and elbow reference frames were calculated in each time frame in the following order:

Global reference frame

Up: Z_G = vertical, as defined by hanging calibration poles
Left: $Y_G = Z_G \times$ [vector from pitching rubber to home plate]
Forward: $X_G = Y_G \times Z_G$

Trunk reference frame:

Lateral: Z_t = vector from leading shoulder marker to the midshoulder
Anterior: X_t = [vector from midhip to midshoulder] $\times Z_t$
Superior: $Y_t = Z_t \times X_t$

Elbow reference frame:

Distal: Z_e = vector from throwing elbow marker to throwing wrist
Medial: $X_e = Z_e \times$ [vector from shoulder joint center to elbow marker]
Anterior: $Y_e = Z_e \times X_e$

Vector S was calculated in the global reference frame as a vector from the throwing shoulder marker to the throwing shoulder joint center. This vector was then expressed as components in the trunk reference frame and labeled as vector S^{Rt}. Vector E was calculated in the global reference frame as a vector from the throwing elbow marker to the throwing elbow joint center and then expressed in the elbow reference frame as vector E^{Re}.

The direction (i.e., unit-length vector) and magnitude were calculated for vectors S^{Rt} and E^{Re} in each data frame. The average magnitude and direction throughout the pitch were calculated for vectors S^{Rt} and E^{Re}. The average magnitude of each of the two vectors was expressed as a fraction of humerus and radius length, respectively. The directions for the vectors S^{Rt} and E^{Re} were then averaged for all subjects. The average magnitudes as a fraction of humerus and radius length were calculated for S^{Rt} and E^{Re}, respectively.

The average magnitude of S^{Rt} expressed in meters was equal to the radius of a reflective marker (0.019 m) added to the length of the pitcher's humerus (in meters) divided by 605. The average direction of this vector was (.413 · armflag, –.903, .121), where armflag was 1 for a right-handed thrower and –1 for a left-handed thrower. Hence,

$$S^{Rt} = (.019 + \text{humerus}/605) \cdot (.413 \cdot \text{armflag}, -.903, .121).$$

The average magnitude of E^{Re} expressed in meters was equal to the radius of a reflective marker (0.019 m) added to the length of the pitcher's radius (in meters) divided by 870. The average direction of this vector was (.800 · armflag, .521, .296). Hence,

$$E^{Re} = (.019 + \text{radius}/870) \cdot (.800 \cdot \text{armflag}, .521, .296).$$

Equations for Each Individual Athlete

In each time frame of each throw, the locations of the shoulder and elbow on the throwing arm were translated from markers to joint centers. First, vectors S^{Rt} and E^{Re} were calculated as shown above. The local trunk reference frame (R_t) was then calculated using the locations of the reflective markers. Then vector S was calculated as follows:

$$\left[\begin{pmatrix} \\ S \\ \\ \end{pmatrix}\right] = \left[\begin{pmatrix} \\ X_t \\ \\ \end{pmatrix}\begin{pmatrix} \\ Y_t \\ \\ \end{pmatrix}\begin{pmatrix} \\ Z_t \\ \\ \end{pmatrix}\right]\left[\begin{pmatrix} \\ S^{Rt} \\ \\ \end{pmatrix}\right]$$

Next, the shoulder joint center location was calculated:

(Shoulder joint center) = (Shoulder marker) + S.

To find the elbow joint center location, the local elbow reference frame (R_e) was calculated using the locations of the reflective markers and the shoulder joint center. Vector E was then calculated as follows:

$$\left[\begin{pmatrix} \\ E \\ \\ \end{pmatrix}\right] = \left[\begin{pmatrix} \\ X_e \\ \\ \end{pmatrix}\begin{pmatrix} \\ Y_e \\ \\ \end{pmatrix}\begin{pmatrix} \\ Z_e \\ \\ \end{pmatrix}\right]\left[\begin{pmatrix} \\ E^{Re} \\ \\ \end{pmatrix}\right]$$

Finally, the elbow joint center location was calculated:

(Elbow joint center) = (Elbow marker) + E.