SOCCER THROW-IN KINEMATICS

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Soccer is played extensively throughout the world. As the popularity of soccer increases in America, a development of the teaching and coaching techniques is needed. Despite the increasing amount of soccer literature, the soccer throw-in skill has been understated. Up to date, only a few studies have assessed the throw-in biomechanically (Lueft, 1965; Kline, 1980; Levendusky, 1982) and have provided some descriptive data concerning kinematics and kinetics. The throw-in is a unique throwing motion in that both hands must be used, the ball must come from behind the head forward, and both feet must maintain contact with the ground until release as stipulated by the laws of the game (FIFA, 1977). As a result, the coordination of the upper body movements and the supporting lower body enable a player to throw for longer distances.

There are generally two types of stances employed when performing the soccer throw-in. The staggered stance, used more commonly for longer throws, involves the thrower facing the field of play with one foot ahead of the other. The square stance involves a side by side foot position with both feet perpendicular to the field of play. There have been two investigations by Vennell (1967) and Wun (1969) which determined that the staggered stance with a short approach generated the maximum throwing distance or range. The purpose of the present study was to evaluate selected biomechanical parameters of the staggered stance throw-in.

INSTRUMENTATION

The present study employed both cinematographic and force analysis techniques to examine the biomechanical principles involved in the long throw-in.

All throws were filmed with a 16 mm-1P Photosonic recording camera. An all white, regulation MITRE soccer ball was used for all trials in order to more easily collect data from the film records. The camera was placed perpendicular to the plane of motion at a distance of 12 meters from the center of the force platform. The camera was set at 100 frames per second. A timing light, which was built into the camera mechanism, operated at 100 Hz and served as an additional check on frame rate. The camera was fitted with a 25 mm lens. The lens was 1 meter from the ground when the camera was in place. The analysis of film records was performed using a Vanguard Motion Analyzer, Model M-16 C, which was interfaced with a computer system. The angular velocities were determined by using the angle measuring screen on the motion analyzer. A computer program assisted with the analysis of body movements, and the computing of the means.

The kinetic parameters were analyzed from data collected from the force analysis instruments. The force platform depicted in Figure 1, measures 40cm x 60cm. It is a Kistler type 9803 six

IDENTIFICATION OF FORCES

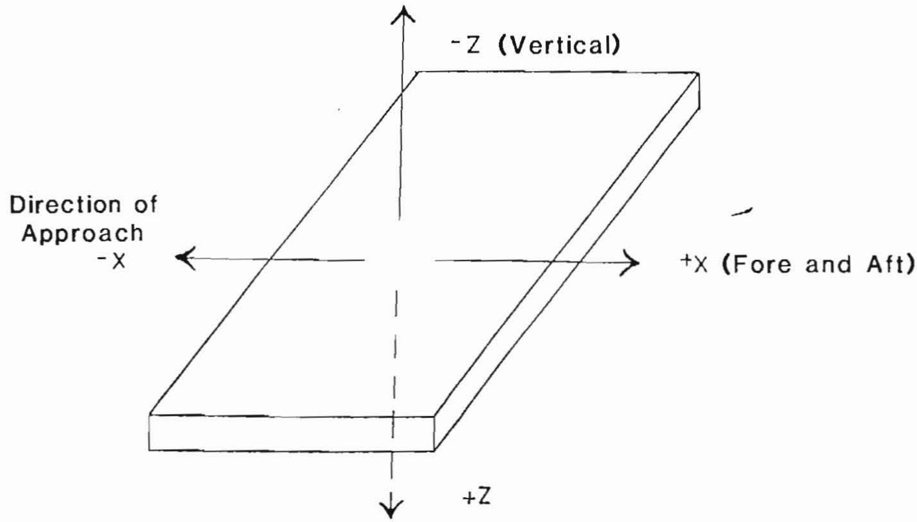

Figure 1. Force platform and identification of ground reaction forces.

component force measuring platform. A Honeywell model 1858 CRT Visicorder was used with the platform to record fore and aft (X) and vertical (Z) forces. Although the lateral (Y) forces were recorded, they were disregarded in the analysis because of minimal effect. The Visicorder was set at 500 newtons of force per major division, and the chart speed operated at four inches per second.

PROCEDURES

Twelve male college varsity soccer players from an NCAA Division II program were selected for this study. All subjects attended a practice session to become accustomed with the procedure for testing. The selected kinematic and kinetic parameters studied in the present study included three main areas of investigation: angular segmental velocities of the upper body joints, ground reaction forces from the throwing surface, and projectile motion factors that affect the flight and distance the ball travels. The mean angular segmental velocities were recorded at .01 second intervals about the hip, shoulder, elbow, and wrist joints beginning at .12 seconds prior to release. The mean ground reaction forces recorded were fore and aft (X) and vertical (Z) forces during time intervals of .01 seconds. The beginning of recording for these forces was .20 seconds prior to release. The projectile motion factors identified and measured were: mean angle of release, mean instantaneous velocity at release, mean height of release, mean estimated distance, and mean actual distance the ball traveled in flight.

After signing an informed consent form, the subjects were instructed to throw naturally for maximal distance on all throws. The subjects made several practice throws, and had their upper body joints marked before testing. These joint markings of the hip, shoulder, elbow, and wrist were utilized in the analysis of segmental angular velocities. The throwing area had a three meter approach area that allowed the subjects to take a moving start before throwing from the force platform. Only the lead foot was able to fully contact the force platform. All throws were performed in a legal manner according to the laws of the game established by the world-wide governing body of soccer, the Federation Internationale de Football Association (FIFA, 1977).

The selection of the best throw for biomechanical analysis was determined by the ball which traveled the farthest. The upper body was treated as a bilateral moving system. The bilateral segmental method, as described by Sanders (1977), considers the body to be comprised of an adjoining system of segments. The angular velocities of each body segment rotating about the hip, shoulder, elbow, and wrist were identified for each subject at .01 second intervals. This provided mean angular velocities for each time interval starting at .12 seconds prior to release.

The force tracings which recorded the fore and aft (X) and vertical (Z) forces provided a record which was similarly divided into .01 second time intervals for analysis. The forces were examined from .20 seconds prior to release to the point of release, and means were calculated for each time interval. The film records provided a total time of contact on the platform by the lead foot from initial contact to the release point. The time recorded on film served as an indicator of force pattern occurence for matching film and force records.

The projectile motion measurements were also measured from the film records. The angle of release, instantaneous velocity, and height of release were determined using the motion analyzer and computer analysis system. The mean for each of these parameters was calculated. Each throw also had an estimated range or distance calculated using the aforementioned factors in an estimated distance formula (Barham, 1978; p. 196). The actual distance was then subtracted from the estimated distance to determine the effect of air resistance on the ball in flight.

RESULTS

The measurement of angular velocities of the upper body segments was made so that data might be made available to compare with other throwing motions. The body was examined as a segmental link system, and the velocities were recorded at the hip (trunk segment), shoulder (upper arm), elbow (lower arm), and wrist (hand) joints. The means were found for each of these joints from .12 seconds prior to release to the moment of release. Table I shows the mean values for each of the upper body joints.

TABLE I. STAGGERED STANCE THROW-IN MEAN ANGULAR VELOCITIES OF UPPER BODY JOINTS (RADIANS PER SECOND)

TIME	HIP (TRUNK)	SHOULDER (UPPER ARM)	ELBOW (LOWER ARM)	WRIST (HAND)
.12	4.44	- .87	- .78	-2.57
.11	4.56	.74	- 5.83	-2.28
.10	4.96	2.55	- 4.21	-1.51
.09	5.37	3.95	- 1.91	- .09
.08	5.94	4.51	1.09	2.06
.07	5.91	5.14	4.23	2.88
.06	6.10	5.76	6.39	2.09
.05	6.10	5.30	9.74	1.04
.04	5.69	4.66	13.58	1.00
.03	5.29	3.76	16.96	.97
.02	4.62	2.94	19.38	2.87
.01	4.10	2.10	21.50	4.54
Release	3.37	1.68	24.43	7.27

The mean peak angular velocities were not totally in sequence from hip to wrist joint, but they do follow similar patterns of other throwing motions. The peaks serve as indicators to show when the body segments were rotating the fastest about the joints. The peak mean angular velocities for the hip and shoulder occured at approximately the same time interval of .06 seconds prior to release. The peak mean value of 6.10 radians per second was recorded for the hip at both .06 and .05 seconds before release, with the shoulder peak mean value of 5.76 radians per second at .06 seconds. These mean peak values are identified with the graphical illustration of the soccer throw-in motion in Figure 2.

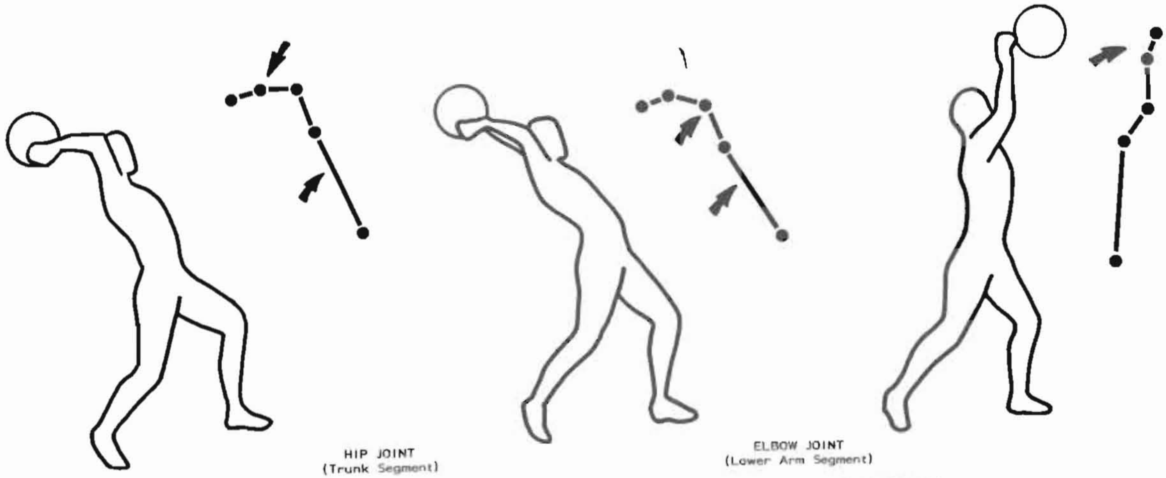

Figure 2. Sequential movement patterns of the throw-in with peak mean angular velocities and time occurence.

As the hip rotated forward initially, the shoulder, elbow, and wrist were rotating in a negative direction. Then the shoulder joint began moving in a positive direction, and the elbow and wrist joints gained larger velocities. The peak mean angular velocities for the elbow and wrist occured at the moment of release. The value for the mean peak angular velocity of the elbow was 24.43 radians per second, and the mean peak angular velocity of the wrist was 7.27 radians per second. The wrist joint showed a slight deceleration prior to the final peak at release. This is indicative of a final cocking of the ball as the other segments were rotating forward in a positive direction.

The fore and aft (X) and vertical (Y) forces measured in this study involved the lead foot placement on the force platform. As the subject planted the foot, a positive fore and aft force occured due to the heel strike pushing forward. The vertical force also occured in a positive direction as some of the player's body weight was supported on the lead foot. The fore and aft force had a mean peak at .12 seconds prior to release of 866.66 Newtons. Afterwards, the remainder of the throw caused a reduced fore and aft force to occur. As the foot flattened out on the ground, and the upper body began the rotation forward, the fore and aft force moved in a downward or negative direction. This can be identified on the illustration of mean fore and aft forces in Figure 3.

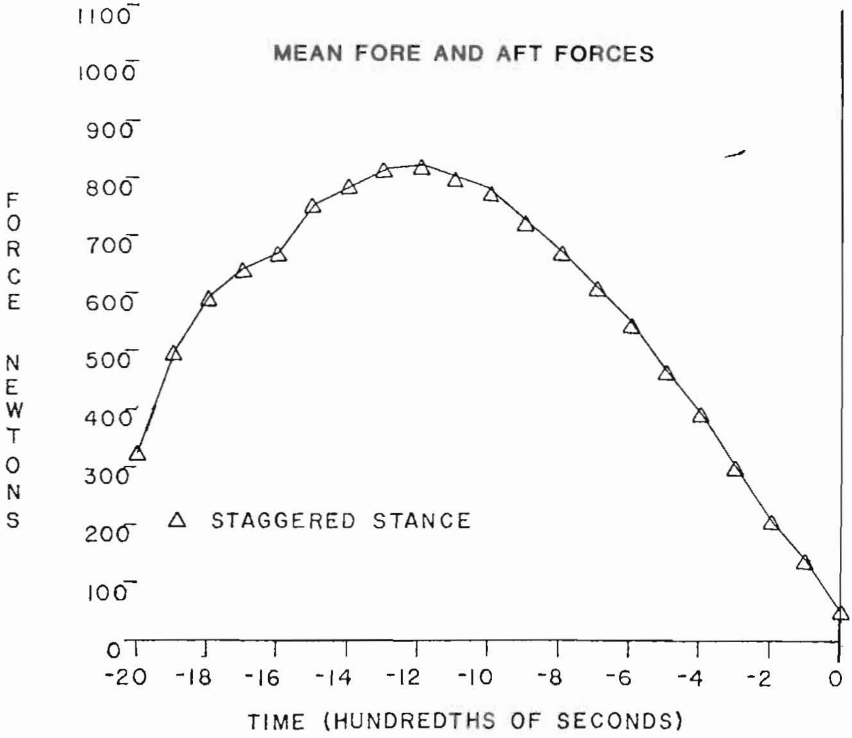

Figure 3. Mean fore and aft forces.

The mean vertical force peaked at .12 seconds prior to release, and moved in a downward, negative direction to the release point. This pattern is displayed in the illustration of mean vertical forces in Figure 4. The body weight began to come

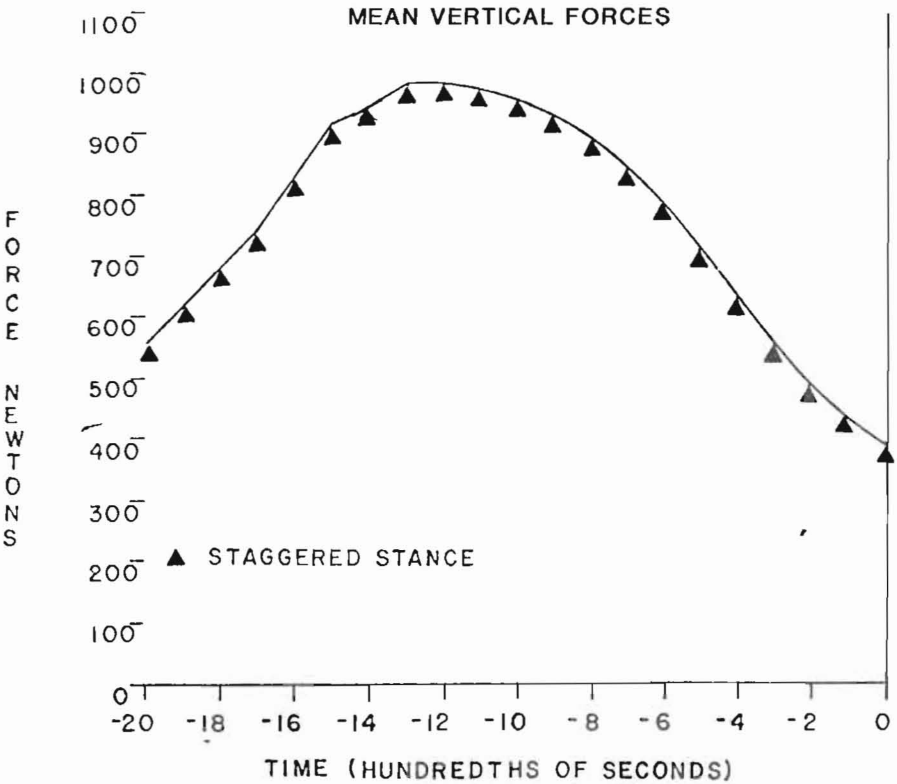

Figure 4. Mean vertical forces.

over the front foot as the body rotated forward, and the body was drawn away from the ground as the ball was released. A mean value of 385 Newtons (84.7 pounds) was found at the moment of release. None of the players had a body weight of less than 130 pounds, so the mean value of 84.7 pounds for the vertical force at release indicates that the body was lifting off of the ground as the upper body rotated quickly above it.

The projectile motion kinematic parameters investigated in this study included angle of release, instantaneous velocity, height of release, and estimated distance. The mean values recorded for the twelve players in this study are shown in Table II. The mean angle of release was 29.17 degrees, mean instantaneous velocity was 18.31 meters per second, and mean height of release was 2.32 meters. The mean estimated distance, calculated by utilizing the previous three data, was 32.38 meters. The mean actual distance was 23.14 meters. The difference between estimated and actual distance was calculated to be 9.24 meters.

TABLE II. PROJECTILE MOTION
KINEMATIC MEAN DATA FOR
STAGGERED STANCE THROW-IN
(N = 12)

	$\overline{X}$	SD
ANGLE OF RELEASE	29.17 DEGREES	4.91
INSTANTANEOUS VELOCITY	18.31 METERS PER SECOND	1.22
HEIGHT OF RELEASE	2.32 METERS	.15
ESTIMATED DISTANCE	32.38 METERS	3.28
ACTUAL DISTANCE	23.14 METERS	3.43
DIFFERENCE	9.24 METERS	

DISCUSSION

The throw-in is designed to limit throwing the ball long distances by requiring simultaneous movement of the upper body segments and continuous contact of the feet with the ground. The throw-in has been typically used to get the ball back into play quickly, and thus, the throw-in for long distances is not commonly used. The need for different strategies to implement an attack has more recently focused attention on the value of using the throw-in for long distances. McKeon and Schmid (1965), Vogelsinger (1973), and Lapshin (1979) consider it important to be able to throw the ball long distances, rather than simply putting the ball back into play. These authors are experienced coaches and realize the potential benefits for long throws.

It has been reported by Cooper, Adrian, and Glassow (1982) and Kreighbaum and Barthels (1985) that throwing motions are involved with proximal-to-distal action of the body segments. O'Connell and Gardner (1972) reported the initiation of the movement by the larger, more proximal body segments. The lighter and smaller distal parts benefit from the transfer of momentum from these larger segments, and then increase in velocity until the important point of release. In normal overhand throwing pattern studies, the body is rotating in different planes of movement, especially in the transverse or horizontal plane. The soccer throw-in, because of it's unique two-handed motion moving the ball to release, has minimal if any rotation along the polar axis. Therefore, almost all movement is restricted to the sagittal plane. As a result, their movement can be recorded with a single camera which provides a two-dimensional view.

The ability to perform a long throw-in allows the team more options when given the opportunity to perform this skill. The use of a running approach aids in throwing for long distances. DiClemente (1968) writes that momentum attained by a short run can be combined with other forces in the forward movement pattern, thereby giving greater power to the ball release, and eliciting longer throws.

The previous studies of ground reaction forces involved in throwing motions has provided some basis for the kinetics studied in this investigation. In the staggered stance throw-in, the lead foot plants, and the upper body rotates forward. A description by Lueft (1965) discusses the combination of stance and body rotation when throwing the ball long distances. The momentum of this rotation caused the body to be drawn upward away from the supporting surface. The use of the force platform also serves as a check to determine if the player broke contact with the ground before release, which is a violation of the law concerning the throw-in. The transfer of momentum from the planting of the feet to the rotation of the upper body parts requires some additional investigation. In the present study, the ground reaction forces indicate that the body uses the lead foot to stop the moving body and translate this momentum to the upper body parts. After the upper body parts begin rotating at a greater velocity, the body is drawn up and away from the ground. This was clearly seen in the results of both vertical and fore and aft forces. Both of these forces diminished in magnitude nearer the moment of release.

Another more recent development in this skill has been the use of a front flip by the thrower to project the ball longer distances then with the conventional stances. The player approaches the touch-line and places the ball onto the ground while performing a handspring flip over the ball. The thrower rotates at very high speeds and lands on both feet, and using both hands, performs a legal throw-in for very long distances. A player from the University of Virginia could throw the ball over 50 yards in games (Gammon, 1982). This unusual skill, which is looked upon unfavorably by FIFA, needs to be studied to determine the magnitude of the velocities generated by this technique. A comparison with the traditional staggered stance throw-in may find significant biomechanical differences.

The study of the projectile motion factors involved with the soccer throw-in were of importance in this investigation because they resulted from many factors. The angular velocities of the upper body and the ground reaction forces all contribute to the final forces imparted to the ball to project it maximum distances. The projectile motion kinematic parameters investigated in this study included angle of release, instantaneous velocity, height of release, and estimated distance.

The instantaneous velocity of the ball at release is of importance in the throw for maximum distance. It has been suggested by Miller and Nelson (1973) that coaches should stress improvement of release velocity at the expense of height of release and release angle. Dyson (1977) explains the importance of instantaneous velocity and angle of release as follows:

1. The speed of release is the factor of greatest importance, as emphasized earlier...
2. For a given speed, the most important variable is the angle of projection (Dyson, 1977; p. 228).

A biomechanical evaluation of a single player performing the throw-in was performed at the University of Delaware by Kline and Samonisky (1981). These investigators used cinematographical analysis to examine several kinematic parameters. The player was filmed from the front, side, and rear for different throws using one camera. Kline (1980) reported the following data and observations:

1. Feet traveled 9 feet (2.7 meters) through step, hop, stride.
2. Ball was released from a height of 6.7 feet (2.01 meters).
3. Angle of release was 25 degrees above the horizontal.
4. Low trajectory increased speed, decreased hang time.
5. Thrown ball traveling 47 miles per hour (21.10 meters per second).
6. Release to target time 2.2 to 2.4 seconds.
7. Release to target distance 35-45 yards (31.85 - 40.95 meters).
8. Ball made 7.5 revolutions in a back spin rotation.

(Paper presented at meeting of NSCAA, January, 1980).

Much of the data from this present study was similar to that presented by Kline. The data support that the variables that can be altered more easily are the angle of release and instantaneous velocity. The throw-in for maximum distance may require the projection angle to be approximately 25 to 30 degrees above the horizontal to attain maximum angular velocities of the moving body segments, and increase the horizontal velocity component of the ball in flight.

At least one soccer ball manufacturer, the W. H. Brine company located in the United States, has addressed the issue of air resistance. They have produced a soccer ball, called the Wind Channeling Ball, that they believe produces a truer flight and is affected less by air resistance.

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