EFFECT OF PROJECTION VARIABLES ON THROW DISTANCE AND FLIGHT TIME IN AN AMERICAN FOOTBALL THROW

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In American football the ball is usually thrown to the receiver with near-maximum speed and a low angle so as to minimize the flight time. In this study a player performed maximum-effort throws using a wide range of projection angles. The throws were recorded by a video camera and a 2D biomechanical analysis was conducted to obtain mathematical expressions for the relationships between the projection variables. These expressions were then inserted into a model of the aerodynamic flight of an American football, and the throw distance and flight time were calculated. We that found the relationships between the projection variables had only a small effect on the projection angle and flight time for a pass to a receiver at a given distance. Players probably get the projection angle in a throw very nearly right through trial-and-error practice.

KEY WORDS: American football, flight distance, flight time, quarterback, throwing.

INTRODUCTION: Passing is one of the most common actions in American football. In most passes the quarterback throws the ball to the receiver in an attempt to progress the ball down the field towards the opposition end zone. The best quarterbacks can throw the ball 60–80 m in a long 'bomb' throw where the aim is to gain maximum distance. However, it is more usual for the quarterback to throw a fast pass to a receiver who is relatively close by and has evaded the opposition players. In such throws the ball is projected at near-maximum speed and at a low angle so as to minimize the flight time of the ball and hence reduce the chance of interception.

In a football throw we expect aerodynamic drag to substantially reduce the distance of the throw and to slightly increase the flight time. In addition, the inter-relations between the thrower's projection variables might have a substantial effect on the projection angle required to attain a given throw distance. Previous studies of throwing for maximum distance in other sports have established that even a small dependence of projection velocity on projection angle can have a very strong effect on the optimum projection angle that produces the greatest distance (Red & Zogaib, 1977; Linthorne & Everett, 2006).

The aim of the present study was to quantify the relationships between the projection variables in a football forward pass. We then investigated whether these relationships have a substantial effect on the optimum projection angle for attaining maximum throw distance. We also investigated whether these relationships have a substantial effect on the projection angle and flight time for a pass that minimizes the fight time to a receiver at a given distance.

METHODS: This study used a single-subject experimental research design (Bates, 1996) in which the projection angle was systematically varied. One male collegiate American football player (21 years, 1.85 m, 78 kg) volunteered to participate in the study. The study adhered to the tenets of the Declaration of Helsinki and was conducted in accordance with procedures approved by our institutional ethics committee. The participant was informed of the protocol and procedures prior to his involvement and written consent to participate was obtained.

The participant performed 21 maximum-effort throws in still air conditions in an outdoor football facility. The throws were performed using an NFL-approved match ball (Nike Spiral-Tech; Nike, Beaverton, USA), and the participant was asked to throw the ball using a projection angle that ranged from 'much higher' to 'much lower' than his preferred projection angle for attaining maximum distance. The order of the projection angles was randomized and an unlimited rest interval was given between throws to minimize the effects of fatigue on performance. For each throw the distance was measured to the nearest 0.1 m using a fiberglass tape measure, and the flight time of the ball was measured using a 50 Hz video camera that was placed about 40 m in front of the participant.

A JVC GR-DVL9600 video camera (Victor Company of Japan, Yokahama, Japan) operating at 100 Hz was used to record the movement of the participant and ball during the release and early flight phase of throw. The video camera was mounted at right angles to the throw direction and the movement space was calibrated with three vertical poles that were placed along the line of the throwing plane. An Ariel Performance Analysis System (Arial Dynamics, Trabuco Canyon, CA, USA) was used to digitize the ball in the video images. Each trial was digitized from the wind-up to at least 10 frames after release. The coordinates of the ball were calculated from the digitized data using the two-dimensional direct linear transform (2D-DLT) algorithm. The projection velocity of the ball was calculated using unfiltered ball displacement data from images immediately after the ball broke contact with the hand. The horizontal component of the ball velocity was calculated as the first derivative of a linear regression line fitted to the ball displacement data, and the vertical component of the ball velocity was calculated as the first derivative of a quadratic regression line (with the second derivative set equal to -9.81 m/s^2) fitted to the ball displacement data (Nunome, Ikegami, Kozakai, Apriantono, & Sano, 2006). The uncertainties arising from the fitted curves indicated that the uncertainty in projection velocity and projection angle were about 0.3 m/s and 0.9° (±95% CI).

For the 21 throws the projection velocity and projection height were plotted against projection angle. Projection velocity (v) was expected to decrease with increasing projection angle (θ) according to

$$v = v_o - a\theta \qquad (1)$$

where v_o is the projection velocity for a horizontal projection angle (θ = 0°) and a is the rate of decrease (Red & Zogaib, 1977). Projection height (h) was expected to increase according to

$$h = h_s + l_a \sin(b\theta) \qquad (2)$$

where h_s is the height of the shoulder, l_a is the length of the throwing arm, and b is the rate of increase in arm angle with increasing projection angle (Linthorne, 2001). Curves of the form of equations 1 and 2 were fitted to the plots, thus giving values of v_o, a, h_s, l_a, and b for the participant. Equations 1 and 2 were then inserted into a mathematical model of the aerodynamic flight of an American football (Linthorne & Everett, 2006; Linthorne & Thomas, 2016), and this model was used to calculate the throw distance and flight time as a function of projection angle. This allowed the optimum projection angle that maximized the throw distance to be identified. The value of the effective drag area of the ball in the mathematical model was obtained by matching the calculated throw distances to the measured throw distances.

The effects of the relationships between the projection variables (equations 1 and 2) on the projection angle required to reach a receiver at a given distance in the minimum time was investigated. Four models were used: 1) a free-flight projectile with a constant projection velocity and projection height; 2) a free-flight projectile with the relationships between the projection variables; 3) an aerodynamic projectile with a constant projection velocity and projection height; and 4) an aerodynamic projectile with the relationships between the projection variables.

RESULTS: As expected, the participant's projection velocity decreased with increasing projection angle (Figure 1a). Part of the decrease in projection velocity was due to using a shorter acceleration path when throwing at higher projection angles, and part appears to have been due to a reduction in the force that the athlete exerted on the ball due to changes in the mechanical arrangement of the participant's musculoskeletal system. The participant's projection height increased slightly with increasing projection angle (Figure 1b), mainly because of the increase in the angle of the participant's arm to the horizontal. The model fit parameter values were v_o = 20.3 ± 1.0 m/s, a = 0.007 ± 0.002 m/s per degree, h_s = 1.77 ± 0.08 m, l_a = 0.58 ± 0.13 m, and b = 0.9 ± 0.6 per degree (±95% CI). Best agreement between the measured and calculated throw distances and flight times was achieved with a drag area of 0.013 m^2. After taking into consideration the complex nature of the flight of the ball, this value is consistent with wind tunnel data on American footballs (Alam, Smith, Chowdhury, & Moria, 2012). The participant's calculated optimum projection angle for attaining maximum

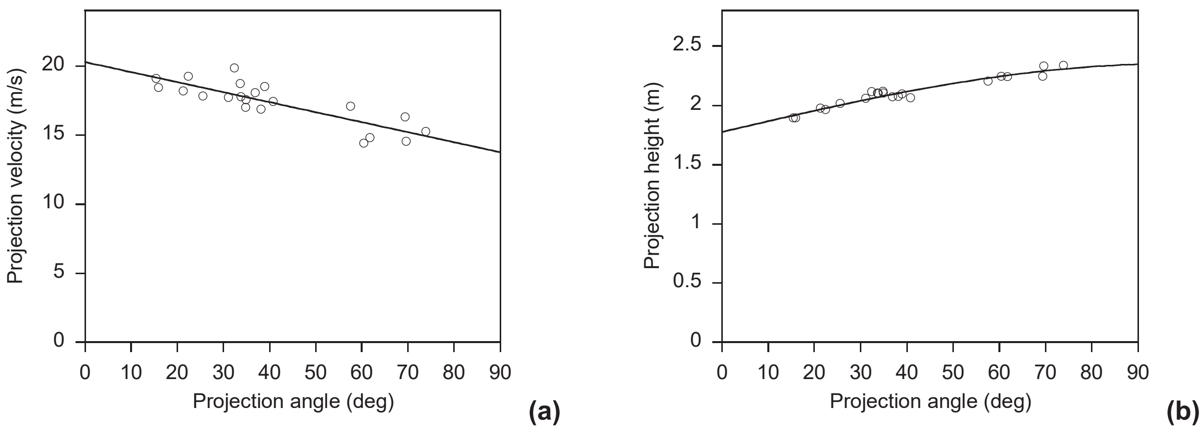

Figure 1: These plots show the effect of projection angle on (a) projection velocity and (b) projection height when throwing an American football. The fitted curves are equations 1 and 2 respectively.

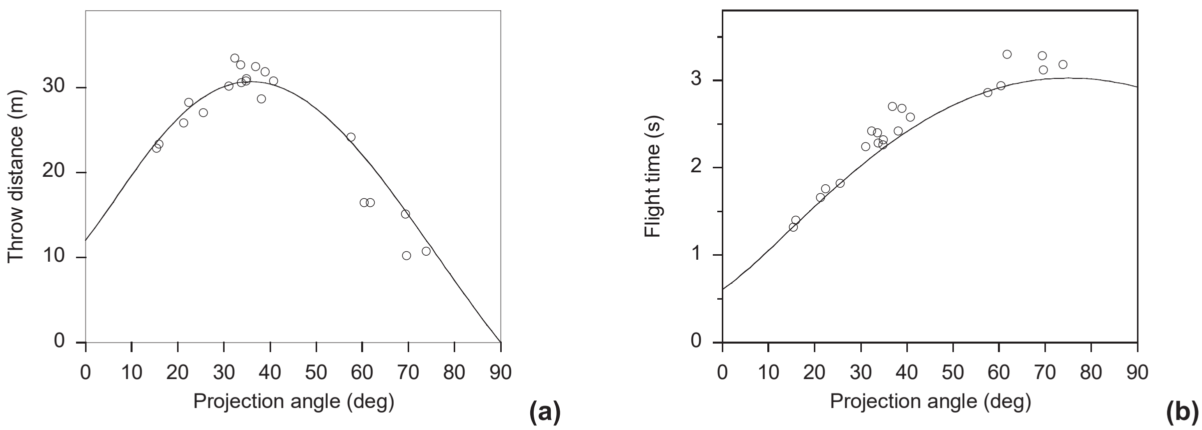

Figure 2: These plots show the effect of projection angle on (a) throw distance and (b) flight time when throwing an American football. The fitted curves are calculated from an aerodynamic model of throwing an American football that includes the relationships between the projection variables (equations 1 and 2). For this participant the optimum projection angle for attaining maximum distance is 36°.

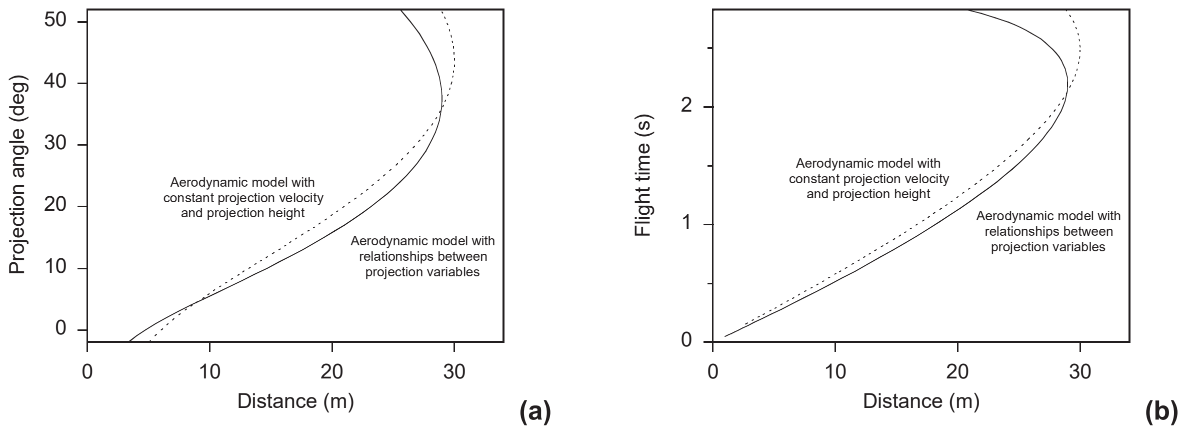

Figure 3: Plot (a) show shows the calculated projection angle required to reach a receiver at a given distance in the minimum time. Plot (b) shows the corresponding flight time. Calculations are for the participant in this study and a catch height of 1.5 m. Solid line = aerodynamic model that includes the relationships between the projection variables (equations 1 and 2); Dashed line = aerodynamic model that has a constant projection velocity and projection height.

distance (35.9°) was considerably lower than 45° (Figure 2) and was in good agreement with his preferred projection angle (36.6 ± 3.5°; mean ± SD).

As expected, the models indicate that projection angle and flight time increase as the distance to the receiver increases (Figure 3). Aerodynamic drag reduces the maximum throw distance by a few metres compared to a projectile in free flight; however, it increases the projection angle required to reach a receiver at a given distance by less than a few degrees. The relationships between the projection variables also have a relatively small effect on the projection angle and flight time required to reach a receiver at a given distance. The decrease in projection velocity with increasing projection angle (equation 1) reduces the projection angle by less than 3° and reduces the flight time by less than 0.15 s (Figure 3).

DISCUSSION: The results from this study confirm that there are strong relationships between the projection variables when throwing an American football. The relationships are similar to those found in previous studies of throwing (Red & Zogaib, 1977; Linthorne, 2001; Viitasalo, Mononen, & Norvapalo, 2003; Linthorne & Everett, 2006). In an American football throw the decrease in projection velocity with increasing projection angle reduces the optimum projection angle for attaining maximum distance to well below 45°. In contrast, the increase in projection height with increasing projection angle has almost no effect on the optimum projection angle. As was found in other ball sports (Linthorne & Everett, 2006; Linthorne & Thomas, 2016), the aerodynamic drag acting on an American football reduces the throw distance but has little effect on the optimum projection angle.

The results from this study indicate that the relationships between the projection variables have only a small effect on the projection angle and flight time for a pass to a receiver at a given distance. Therefore, we conclude that the relationships have little practical influence on throwing an effective short pass in American football. We assume that players can get the projection angle for a fast pass very nearly right simply through trial-and-error practice.

Although our study used only one participant, the throwing technique used by the participant was similar to that used by other skilled players. Therefore, it appears likely that the results from the present study would apply to other adult male players of similar standard.

CONCLUSION: In a football forward pass the projection velocity that a player can produce decreases as the projection angle is increased. This relationship reduces the optimum projection angle for achieving maximum distance to well below 45°. The relationships between the projection variables have only a small effect on the projection angle and flight time for a pass to a receiver at a given distance.

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