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How loud would a footballer need to shout to defend a shot?

Rikesh Kunverji
Natural Sciences (Life and Physical Sciences), School of Biological Sciences, University of Leicester
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Abstract
During the 2-0 victory over rivals Tottenham Hotspur, Arsenal's Benjamin White was spotted shouting at an attacking player as a means of last-ditch defending. This paper assumes that shouting was an effective means of defending, and calculates an estimate of how loud the shout would need to be to force the ball to roll quicker, causing the shot to go askew. White would have had to shouted at an unphysical value 157.8dB, comparable to the sound of a military jet taking off, in order to defend using his vocal cords.

Keywords: *Sports; Physics; Acoustics; Football*

Introduction

The North London Derby, Arsenal vs Tottenham Hotspur, is an extremely heated fixture on the Premier League calendar between two neighbouring rival clubs. Arsenal travelled away to Tottenham for the 15th January 2023 fixture, and were convincing 2-0 winners [1]. In the 53rd minute of the match, a Tottenham player ran clear of the Arsenal defence, through on goal and forced an excellent save from Arsenal goalkeeper Aaron Ramsdale. However, replays also showed that Arsenal's Benjamin White, the defender who chasing back at the time, was seen shouting in the direction of the attacking player, as seen in Figure 1.

The player was clearly perturbed by the sound of the shout, losing concentration at a crucial moment, somewhat slicing the shot. According to the International Football Association Board (IFAB) Laws of the Game, Law 12.1, this is an offence by the defending player, who should also receive a caution for unsporting behaviour, as White is "*distracting the opponent verbally during play*" [2]. However, could it be possible that the shout itself caused an unpredictable connection with the ball? In this paper, the minimum sound pressure required to cause a shot to be sliced – not struck cleanly as the player intended – will be calculated. This makes the assumption that the sound pressure distributed over the surface of the ball will cause a force to act on the centre of mass, and due to friction between ball and grass, cause an increase in angular acceleration. It will also be assumed that a shot would have been struck properly if the shout did not cause the ball to roll quicker.

Figure 1 – Benjamin White shouting towards a Tottenham attacker, to prevent the player from making a clean contact with the ball. (Photo credit: Sky Sports [1]).

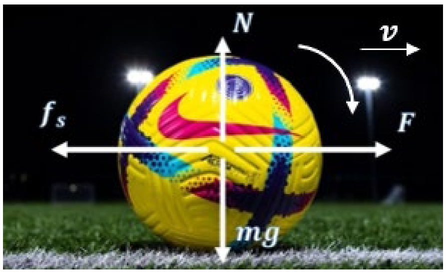

Figure 2 – Free-body diagram showing the forces on the football, as well as direction of rotation, where f_s, N, F, mg are the forces of static friction, normal, the shout and gravity respectively. (Photo credit: Adapted from Nike).

Derivation

To derive the volume of the shout, Equations 1 & 2 resolve the force and torque in the direction of movement, as described in Figure 2:

$$F - f_s = ma, \quad (1)$$
$$\tau = I\alpha = f_s R, \quad (2)$$

where m is the mass and I is the moment of inertia of the football. It is assumed that the ball is rolling without slipping with a constant angular velocity over slick grass. Substituting Equation 1 into the rolling without slipping condition gives:

$$\alpha = \frac{a}{R} = \frac{F - f_s}{mR}. \quad (3)$$

Equation 3 can then be substituted into Equation 2 to give:

$$I\left(\frac{F - f_s}{mR}\right) = f_s R. \quad (4)$$

Assuming the football to be a smooth sphere, the moment of inertia of a sphere is given by [3]:

$$I = \frac{2}{5}mR^2. \quad (5)$$

Substituting this back into Equation 4 and solving for the shouting force F required gives the result:

$$F = \frac{7}{2}f_s = \frac{7}{2}\mu_s mg, \quad (6)$$

where μ_s is the coefficient of static friction between the ball and grass, and has been measured to be 0.63 in a Nike ball [4]. The mass of the ball will be assumed to weigh 430g, as per IFAB regulations [5].

$$F_{sound} = \frac{7}{2}\mu_s mg = 9.30N. \quad (7)$$

Substituting these values in results in a force of 9.3 N, which will be incident over one hemisphere of the ball - the side that is exposed to White – as calculated in Equation 8. The radius of the ball will be taken to be 11 cm as per IFAB regulations [5].

$$P_{sound} = \frac{F_{sound}}{2\pi R^2} = \frac{9.30N}{2\pi(0.11m)^2} = 122.3\ Pa. \quad (8)$$

Since acoustic energy is related to the amplitude of the sound waves, taking the root-mean-squared pressure for a better estimate of the average sound pressure differential [3], as seen in Equation 9:

$$P_{rms} = \frac{P_{sound}}{\sqrt{2}} = 86.50\ Pa. \quad (9)$$

This value can then be used to work out the sound pressure level (SPL) in decibels, where P_0 is the reference sound pressure [6] – 20 μPa.

$$SPL = 20\log_{10}\left(\frac{P_{rms}}{P_0}\right) = 132.7\ dB. \quad (10)$$

The sound pressure level value of 132.7 dB is what would be required for White to have made an 'tackle' by shouting, and is comparable to the sound of artillery fire from a distance of 3 m [7]. As seen in Figure 1, White looks to be around 1.8 m away from the Tottenham player when he begins to shout. As sound attenuates following the inverse square law, Equation 11 [8] can be used to calculate the reduction in sound as the sound propagates further from source.

$$\Delta SPL = 20\log_{10}\left(\frac{1.8m}{0.1m}\right) = 25.1\ dB \quad (11)$$

In the case of White shouting at a player from a much closer distance of 10 cm, instead of 1.8 m in this example, the sound would be 25.1 dB louder.

Conclusion

Evaluating Equation 11 using the previously calculated sound pressure level of 132.7 dB, and adding 25.1 dB due to vicinity, results in a shout of at least 157.8 dB from White in order to have affected the shot. This is not quite loud enough to kill – which would most likely resulted in a long suspension for White – but is far beyond the threshold of pain, and enough to instantly rupture the opponents eardrums. It is also important to note that the loudest a human has produced is 129 dB [9], and the value of White's inhuman shout much louder, comparable to the take-off of a military jet [7].

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