Deflation in NFL Footballs from Weather Conditions

Objective: To investigate how the internal air pressure of footballs used during the first half of play in the NFL American Football Conference Championship Game on January 18, 2015 may have been affected by weather and/or field conditions.

Design: Recreate in a controlled laboratory the game-day conditions (temperature and rain) to simulate the environment that the footballs may have been exposed to.

Settings: Laboratory environment with two control rooms; a "hot room" set to 75°F (degrees Fahrenheit) and a "cold room" set to 50°F.

Main Outcome Measurements: Measured football internal air pressure in the "hot room" and in the "cold room" environments both with and without exposing the footballs to water. Furthermore, temperature measurements were monitored to maintain appropriate control conditions.

Results: HeadSmart Labs found that on average the footballs dropped 1.07 psi (pounds per square inch) from the 25°F temperature change alone (75°F "hot room" minus 50°F "cold room"). It was also discovered that when a football was exposed to water, the pressure dropped an additional 0.75 psi. In combination, it was found that from exposure to simulated game-day elements, the air pressure in the footballs decreased by an average of 1.82 psi with a max of 1.95 psi.

Conclusions: Footballs used during the American Football Conference Championship game may have lost up to 1.95 psi due to temperature and field conditions alone.

Key Words: DeflateGate

On January 18, 2015, the New England Patriots faced off against the Indianapolis Colts at Gillette Stadium (Foxborough, MA) in a game that would determine which team would earn a spot to play in the Super Bowl. The Patriots won the game, however the postgame antics have been of great interest to the public. After an Indianapolis Colts' defensive player intercepted the ball, the Colts noticed that the ball had been underinflated. Allegedly, this initial finding led the game officials to measure the air pressure of the Patriots' footballs during halftime. It was further reported that pressure measurements taken by the game officials during halftime found 11 of the 12 game footballs were underinflated, as low as 10.5 psi. The NFL requires that all game footballs be inflated within the range of 12.5-13.5 psi. This news sparked an investigation led by the NFL as well as numerous Patriot-sponsored press conferences, national news coverage, and accusations of the Patriots playing unfairly.

In an effort to shed light on the controversy, HeadSmart Labs has applied a scientific approach to analyzing the issue. Our idea was to understand the affects of weather and field conditions on a football's air pressure. Our Lab set out to discover whether environmental conditions alone could have deflated the footballs by as much as 2 psi.

MATERIALS AND METHODS

Before speaking about the experiment methodology, it is important to understand when and where the footballs traveled throughout the course of the game, from initial referee inspection until halftime. The goal of our experiment is to take 12 authentic NFL footballs and simulate this journey in an effort to understand how weather and field conditions affect air pressure in the footballs. Below you will find Table 1, which outlines the game day timeline.[2]

TABLE 1. Game Day Timeframe

Actions	Game Time	Simulation Time
Official Certifies Balls	4:25 PM	0:00
Kickoff	6:51 PM	2:26
Halftime Begins	8:30 PM	4:05
Halftime Ends	8:43 PM	4:28
Game Ends	10:04 PM	5:49

A total of 12 authentic NFL footballs were used for this study, along with two temperature-controlled environments. The temperature-controlled "hot room" simulates a locker room environment set to 75°F. To determine what temperature to set the "cold room" to, the Lab decided to look at weather data

from the two closest weather stations to Gillette Stadium, Norwood, MA and Pawtucket, RI. Norwood is located 7.8 miles north-north-east of Gillette Stadium, while Pawtucket is 13.3 miles south-south-west of the stadium.[1] In Table 2, you can see the different temperatures at their respective times throughout the game.[3]

TABLE 2. Gillette Stadium Nearby Weather Data

Norwood MA 7.8 Miles NNE		**Pawtucket RI** 13.3 Miles SSW	
Time	**Temperature (°F)**	**Time**	**Temperature (°F)**
3:53PM	53.1	3:55PM	48.2
4:54PM	52.0	4:55PM	48.2
5:53PM	52.0	5:55PM	48.2
6:53PM	52.0	6:55PM	48.2
7:53PM	51.1	7:55PM	50.0
8:53PM	52.0	8:55PM	48.2
9:53PM	48.9	9:55PM	46.4

Since there is no weather data from Gillette Stadium, the Lab averaged weather data from these two cities, and concluded that the "cold room" environment should be 50°F. These weather estimations can be found below in Table 3.

TABLE 3. Gillette Stadium Estimated Temperature

Time	**Temperature (°F)**
4:00PM	50.7
5:00PM	50.1
6:00PM	50.1
7:00PM	50.1
8:00PM	50.6
9:00PM	50.1
10:00PM	47.7

We began our study by having all 12 footballs in the "hot room" where they were inflated to 12.5 psi. This simulated when the referees would have inspected the footballs before the game in their locker room. This process usually takes place 2 hours and 15 minutes before game time but since the game was delayed there was an additional 11 minutes before kickoff. Once the footballs were inflated, they were then moved to the "cold room" to simulate the footballs being moved outdoors and onto the field.

Once 2 hours and 26 minutes passed, we measured the pressure in all the footballs. This demonstrated how much pressure was lost due to temperature changes. After taking our first readings, we dampened the footballs to simulate the rainy weather during the game. This was done by manually rotating each of the footballs in 50°F water baths and blotting them with a damp towel until the footballs were thoroughly saturated. Measurements of football inflation pressure were taken every 30 minutes after saturation. From Table 1 we know that halftime takes place in between our 90 minute and 120 minute after kickoff pressure readings. The readings from these two times gave us an estimation as to what impact environmental conditions could have had on the game footballs.

For our testing, we used a calibrated Molten PGP Deluxe Digital Air Gauge with a needle moistened by glycerine. While testing, the footballs were placed on a metal wire shelf to allow airflow over them. In addition, there were fans circulating air around the footballs to simulate the windy game conditions.

RESULTS

After letting the footballs cool in the "cold room" for 2 hours and 26 minutes (to simulate the time period between when the referees inspected the footballs and kickoff), the Lab found that the 12 footballs had experienced a drop in pressure. See Table 4.

TABLE 4. 50°F Dry Football Pressure

	Start of Game
Average	11.43 psi
Minimum	11.35 psi
Maximum	11.50 psi

From the table above, it can be seen that the average pressure drop of the 12 footballs was 1.07 psi (12.50 psi minus 11.43 psi) below the starting pressure.

The next step in the experiment was to mimic the effects of the wet field conditions. In Table 5, we can see the different pressures in the footballs from both 90 minutes and 120 minutes after the footballs were saturated in water.

TABLE 5. Simulated Halftime Pressure Readings

	90 Minutes from Kickoff	**120 Minutes from Kickoff**
Average	10.70 psi	10.68 psi
Minimum	10.55 psi	10.55 psi
Maximum	10.80 psi	10.75 psi

In Table 4 and Table 5, it can be seen that there was an additional average pressure drop within the footballs of 0.75 psi (11.43 psi minus 10.68 psi).

DISCUSSION

As articulated in the results section of this paper, the footballs experienced a 1.07 psi average pressure drop due to changes in temperature. This can be explained using a simplified version of the Ideal Gas Law, Gay-Lussac's Law.[4] The law assumes a fixed mass of gas at constant volume:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

This relationship between temperature and pressure is direct; as temperature decreases, pressure decreases. To check the experimental results, the equation can be used to determine what the initial temperature would need to be in order to see this pressure change. The equation is outlined below:

P_1 = 12.50 psi gauge (27.20 psi absolute)
P_2 = 11.43 psi gauge (26.13 psi absolute)
T_2 = 50°F (509.7° Rankine)

With these variables, we can determine T1:

$$\left(\frac{P_1}{P_2}\right) * T_2 = T_1$$

$$\left(\frac{27.20 psi}{26.13 psi}\right) * 509.7R = 530.6R = 70.93°F$$

These results are relatively similar to what we would have expected to see since our initial "hot room" temperature was at 75°F.

Next we will look at the pressure loss due to the affects of water. When materials such as leather get wet, they absorb water and tend to expand. When the leather and the woven fabric lining of the football became wet, we can conclude that the volume of the football increased which reduced the pressure in the footballs. We can use Boyle's Law in order to calculate the percent volume change that the football will experience.[4] The equation is outlined below:

P_1 = 11.43 psi gauge (26.13 psi absolute)
P_2 = 10.68 psi gauge (25.38 psi absolute)

$$(P_1) * (V_1) = (P_2) * (V_2)$$

$$\frac{V_2}{V_1} = \frac{P_1}{P_2} = \frac{26.13 psi}{25.38 psi} = 1.030$$

From this we can conclude that the volume of the football would have expanded by 3.0% in order to account for this pressure decrease.

SUMMARY

These findings support the fact that due to the rainy conditions and a 25°F decrease in the footballs' temperatures, it is expected that the footballs would experience a pressure decrease of about 1.82 psi.

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