Investigating the relationship between physical properties of a football and player perceptions

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Abstract

Football being one of the most popular sports globally sees the emergence of new ball products and technologies on a regular basis, with the governing body FIFA having set a standard to ensure consistency between products. Despite this, differences are commonly perceived between footballs. The aim of this study was to evaluate players’ perceptions in relation to direct and objective measurements of footballs. A paired comparison method was used to evaluate players’ perceptions of hardness and weight during passing and shooting exercises of three individual FIFA Approved footballs. Direct measurements of mass and Shore A hardness were obtained as well as quasi-static stiffness values and diameter normal compression ratios during kicking robot impacts. Players perceived with significance, differences between the footballs in respect to hardness for the passing exercise. No initial trends were seen between perceptions of hardness and weight and direct measurements of hardness and mass. An emerging trend between perceptions of hardness and weight and objective measurements of quasi-static stiffness and high-speed impact diameter normal compression ratio was seen suggesting players’ perceptions of hardness and weight are more complicated than purely direct measurements of mass and hardness.

Nomenclature

NCR  ball diameter normal compression ratio
HSV  high speed video

1. Introduction

The game of football is one of the most popular sports worldwide, with the 2014 FIFA World Cup watched by over 3.2 billion television viewers [1], and club sponsorship deals in 2015 exceeding £70 million a year in the English Premier League [2]. The ball is a fundamental requirement for any football match to be played and a highly lucrative and competitive market for balls has developed. With the advancement of materials and manufacturing techniques leading to continuous emergence of new ball products, the governing body, in an attempt to ensure fair competition and consistency for the players, introduced a series of performance standards, known initially as the FIFA Quality Concept (1995) and more recently rebranded as the FIFA Quality Programme [3]. This standard outlines requirements for a ball to be deemed appropriate for sanctioned football competitions, covering parameters including mass, circumference and sphericity among others. It is nevertheless typical, for players to report perceived differences between footballs, through criticism in the media [4] as well as through scientific study [5]. Players are
known to use terms such as *hardness* and *weight* when describing the feel of a ball [5], although it is unknown whether these correlate with engineering measurements of these quantities or are based on other factors. It is widely known that brands are seeking to further their understanding of how design parameters relate to consumer opinion in order to gain a competitive advantage. Understanding how objective measurements of footballs relate to players’ perceptions will aid development of products that match the demands of the consumer.

The few studies that have been carried out into players’ perceptions of sports balls have used different experimental methods that vary in the complexity of the task for the player. The scaled response technique, for example, requires subjects to score products using a scale for different attributes but this often places a large emphasis on the ability of a player to remember their perceptions of other products included in the test across many trials. The paired comparison method [6] only necessitates subjects to recall the most immediate interaction, making it a simple evaluation task for a subject. The paired comparison method requires subjects to interact with samples and provide a fixed response in the direction of difference, as opposed to assigning a magnitude of the difference. Several studies [7,8] have also permitted a ‘no difference’ response from subjects, which aims to limit the ‘guess’ responses in the data.

To the extent of the authors’ knowledge, no study has sought to correlate objective measurements of ball hardness and mass to players’ perceptions of *hardness* and *weight*. However, it has been reported in previous studies in hurling [9] and tennis [10] that players’ perception of *hardness* correlates most closely to ball stiffness, and in tennis [8] that players’ perceptions of *weight* and *hardness* relate best to measures of ball stiffness and damping obtained through high-speed impact. Given the nature of the polymeric materials typically used in sports ball construction, it is important to ensure that the loading rate during assessment of ball stiffness is relevant to the conditions typical during play [10,11]. For this reason, a range of ball properties, including mass, Shore A hardness, quasi-static compressive stiffness and deformation under dynamic loading are measured objectively and analysed to explore potential relationships. The aim of this research was to evaluate a range of objective physical measurements of footballs and relate these to players’ perceptions.

2. Methods

For this initial study, it was decided that perceptions of *hardness* and *weight* of footballs would be the focus, since these terms are considered to be the most common perceptions reported in football as well as other sports. The inclusion of only two attributes for the evaluation task would also be simpler for the test subjects. Players are regularly required to perform pass style kicks, shot style kicks, dribble and head the ball. Impact testing and finite element modelling has shown that ball orientation may influence rebound [11], and it was unknown whether this effect could be perceived by players. Heading and dribbling were removed as exercises in order to limit the ball orientation for this preliminary study. Passing was found to be the most common action within a game excluding controlling a pass [12], therefore emphasis was placed on the passing exercise for this study, with the shooting exercise being a secondary task. Three individual balls were selected for testing. Therefore any relationships evaluated are limited to the three specific balls tested, as it is unknown how much intra-model variation is present within a batch of footballs from a single model.

2.1. Ball selection

Three individual balls were selected for this study (see Table 1), each a different ball model manufactured using a different construction method and materials. The ball models are all currently used in several professional leagues globally and at the time of testing all were approved by the governing body FIFA for use in matches.

| Ball       | 1  | 2  | 3 |
|------------|----|----|---|
| Manufacturer | adidas | Nike | Derbystar |
| Model      | Brazuca | Ordem II | Brilliant APS |
| Panel no.  | 6  | 12 | 32 |
| Panel construction | Thermally bonded | Fuse welded | Machine stitched |
| Carcass design | 6 panel - no stitch | 12 panel - stitched | Integrated |
| Bladder    | Butyl | Carbon latex | Carbon latex |

To ensure consistent impact location and compression orientation, the valve was placed in contact with end effector for objective testing, and directly towards the player during the kicking exercises. A single ball inflation pressure of 0.9 bar was also selected. This pressure was within the manufacturers’ recommendations for each of the ball models, as well as within the FIFA regulations of 0.6 - 1.1 bar [3].

As well as the constructions of the footballs, the visual aesthetics of the balls also varied. It has been reported that the appearance of an object may directly influence [13] or invoke preconceptions [5] that influence a subject’s perceptions. A unique post-
production application of camouflage prior to subjective and objective testing, helped disguise the geometry of the panels and brand logos which could have been used to identify the ball type, thus limiting the contribution of the visual design towards players’ perceptions (see Figure 1).

Fig. 1. Application of camouflage to three FIFA Approved footballs (a, d) Ball1 (b, e) Ball2 (c, f) Ball3

2.2. Measurement of subjective data

A two stage approach was used to elicit the players’ perception. A repertory grid [14] style technique was used which allowed for players to give unbiased feedback during the warm-up. The aim of the warm-up was for players to express perceptions of hardness and weight without being forced. Pre-defined questionnaires can contain questions that are irrelevant to a player or suggest attributes that the player would otherwise not have considered. Each subject would begin the warm-up exercise by passing a FIFA Approved ball inflated to 1.1 bar to a test assistant ten times, followed by passing a ball inflated to 0.5 bar ten times. Players were then prompted to respond to the question “How do you perceive the footballs? Please use any terms you would regularly use”. All players responded with terms such as soft or hard, heavy or light, and if players used equivalent terms further discussion was required to clarify term meaning.

The second stage involved the use of the paired comparison method which has been successfully used in previous psychometric studies. Players were asked to compare two footballs at a time and give feedback. For this study each subject was asked to answer the questions:

1) “How do you perceive the hardness of the footballs?”

2) “How do you perceive the weight of the footballs?”

Importantly the questions were not directional, allowing players to not be influenced by the style of question. Players were permitted to answer with options “A is harder than B”, “B is harder than A” or “I perceive no difference”, and “A is heavier than B”, “B is heavier than A” or “I perceive no difference”. To analyse the paired comparison data a rank sum was calculated for each ball [6]. Tukey’s Honestly Significant Difference (HSD) was used to identify significant differences in the rank sums. Two balls whose rank sums differed by more than Tukey’s HSD value can be considered to differ significantly.

2.3. Subjective evaluation test procedure

Six male subjects aged 26.5 ± 4.6 years participated, all playing for German League teams (4th-6th division) at the time of testing. All players wore their own commercially available football boots throughout testing.

All tests were performed in an indoor testing environment on an artificial grass pitch, selected to provide a consistent kicking surface. In order to focus players on the impact feel when performing the passing exercise, players were asked to kick under a bench on which a 2 m screen was mounted to block their view of events after foot to ball contact, limiting the visual cues from the pass.

When performing the shooting exercise, players were asked to kick into a futsal goal from 2 m to minimise ball flight. For the passing exercise, each player performed a single kick for each ball per pair comparison, subjects then answered the subjective evaluation questions. Players repeated each pair comparison to take player reliability into account. For the shooting exercise, the same procedure was followed, but the players would not repeat the task for each pair.

2.4. Objective measurement of footballs

Measurements of the ball mass were taken using an Ohaus EB series digital scale. Each ball was weighed five times and the results averaged. For assessment of quasi-static stiffness, an Instron 5569 device was used to load each ball at 200 mm/min to a peak of 2000 N, selected to represent the impact force of an instep kick [15]. Five trials were performed and the force-time and displacement data recorded and averaged for five trials. Stiffness \( k \), was calculated from Hooke’s law for each ball from the peak force-time recorded, \( F \) and the displacement, \( x \) at given peak force.

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F = kx
\]
As well as quasi-static compression, high-speed dynamic impacts were performed, allowing for impact deformation to be determined. A bespoke Kicking Robot was selected [16] to impact the ball with a kicking leg speed of 11 m/s representative of a short pass and 17 m/s selected for a shot-style kick [12]. Two types of end effector were selected for this testing with the aim of representing the contact areas seen during different style kicks. A circular flat plate with a surface area of $38 \times 10^3 \text{ mm}^2$ was used to be representative of the inside of the foot when passing and a 90 mm diameter cylinder (height 215 mm) orthogonal to the line of force was used for a ‘laces’ kick. Each ball was impacted at each foot velocity with the respective end effector five times. For this study, a Photron SA1.1 high speed video (HSV) camera recording at 5000 fps and 1/10000 s shutter speed, was set-up orthogonal to the line of force with an opaque white, back lit sheet set-up behind the ball to create a sharp outline of the ball.

![Diagram demonstrating diameter normal compression ratio](image)

Fig. 2. Demonstrating how diameter normal compression ratio variables were derived from HSV recorded images

Several different deformation metrics have been reported in literature, centre of mass (COM) displacement and diameter normal compression ratio (NCR), both commonly reported metrics [9]. Diameter normal compression ratio was selected for this study, given the inability to record force-time data in this study. The diameter of the image of the ball taken immediately prior to impact $(do)$ was compared to that in the frame depicting maximal deformation during contact $(dn)$, from this the diameter normal compression ratio was calculated.

$$\text{diameter normal compression ratio} = 100 \times \frac{do - dn}{do}$$

Deriving diameters from the HSV footage is demonstrated in Figure 2. NCR values were calculated for each ball and impact condition and averaged.

Shore A hardness was selected as the hardness metric as it is used by ball manufacturers in assessing the foam layer material properties during production. In order to assess the Shore A hardness of each ball, a section of each ball was removed after all other testing, which included all material layers, since the confines of the test equipment required flat material samples. Each sample was tested five times using a Shore Scale Durometer Hardness Tester, with the mean being calculated.

For each of the objective test data sets, an ANOVA single factor statistical test was run to determine significant difference between the balls $(\alpha=0.05)$. Tukey’s HSD post-hoc test was then performed to identify which balls were significantly different.

### 3. Results

#### 3.1. Subjective evaluation

The calculated Tukey’s HSD values have been plotted as error bars $(\pm 0.5 \text{ HSD})$ to the ranked sum data for the passing exercise; if the bars for two footballs do not overlap then those balls can be considered to differ significantly at the 0.1 level of significance. The rank sum $(\pm 0.5 \text{ HSD})$ is shown for each ball for the passing exercise in Figure 3.

For the passing exercise, Ball1 and Ball3 were perceived to be significantly harder than Ball2, but no significant differences were perceived in respect to weight. For the shooting exercise no significant differences were found in the data.
3.2. Objective measurements

ANOVA showed significant variation between balls for all data sets (α=0.05). The post hoc Tukey test showed the mass, hardness and stiffness to differ significantly between all 3 balls. It can be seen from Table 2 that the mass varied by 8 g for the range of balls selected, Ball 2 weighed the most and Ball 3 the least. Shore A hardness measurements found Ball 3 to be the hardest, Ball 2 was the softest, with Ball 1 lying in the middle. Quasi-static testing showed Ball 1 to have the highest quasi-static stiffness, 22.79 % stiffer than Ball 2 and 16.38 % stiffer than Ball 3. For the 11 m/s NCR results, the Tukey test showed that Ball 1 differed significantly from Ball 2, and Ball 2 differed significantly from Ball 3; Ball 1 and Ball 3 did not differ significantly. For the 17 m/s NCR results Ball 1 and Ball 2 differed significantly; Ball 3 did not differ significantly from either of the other balls. Ball 1 had the smallest NCR for both of the different impact scenarios, Ball 2 exhibiting the greatest NCR. The high speed impacts elicited greater relative difference between Ball 2 and 3 when compared to the quasi-static compressions, although rank order remained the same.

Table 2 Objective measurements of mass, hardness, stiffness and NCR.

| Ball | Mass (g)   | Shore hardness | Stiffness (N/mm) | NCR (%) 11 m/s | NCR (%) 17 m/s |
|------|------------|----------------|------------------|----------------|----------------|
| 1    | 444 ± 0.23 | 15.84 ± 0.70 A | 38.36 ± 0.27     | 8.01 ± 0.12    | 27.64 ± 0.28   |
| 2    | 445 ± 0.15 | 12.56 ± 0.39 A | 31.24 ± 0.11     | 9.39 ± 0.27    | 29.31 ± 0.49   |
| 3    | 437 ± 0.21 | 29.40 ± 1.62 A | 32.96 ± 0.37     | 8.52 ± 0.24    | 28.25 ± 0.70   |

3.3. Comparison between objective measurements and subjective evaluation

No recognisable relationships were found between the subjective and objective measures of semantically equivalent parameters. That is to say no linear trend was found between perceptions and measures of hardness and weight for the balls tested. Figure 4 shows objective measurements of hardness and mass plotted against perceived hardness and weight; it can be seen that there is no clear trend between the data sets.

![Fig. 4. (a) Objective measurement of hardness (± 1SD) against rank sum of hardness (±0.5 Tukey’s HSD) (b) Objective measurement of mass (± 1SD) against rank sum of weight (±0.5 Tukey’s HSD)](image-url)
Quasi-static stiffness and NCR values obtained from high-speed kicking robot impacts are plotted against players’ perceptions. The trend between stiffness, NCR and perceived hardness and weight during the passing exercise, may be an initial suggestion that these metrics are indicative of players’ perceptions of hardness and weight when kicking (see Figure 5).

![Graphs](https://via.placeholder.com/150)

**Fig. 5.** (a) Quasi-static stiffness (± 1SD) plotted against rank sum of hardness(±0.5 Tukey’s HSD) (b) 11 m/s impact NCR (± 1SD) plotted against rank sum of hardness (±0.5 Tukey’s HSD) (c) quasi-static stiffness (± 1SD) plotted against rank sum of weight (±0.5 Tukey’s HSD) (d) 11 m/s impact NCR (± 1SD) plotted against rank sum of weight (±0.5 Tukey’s HSD)

4. Discussion

This research set out to evaluate a range of objective physical measurements of footballs and relate these to players’ perceptions. Rank sums calculated for the subjective evaluation feedback along with calculation of Tukey’s HSD values showed that players perceived Ball 1 and Ball 3 to be harder than Ball 2 (α=0.1), however perceived weight was not shown to differ significantly between the balls. Roberts et al [5] found that players are able to perceive balls to be different in respect to both of these characteristics. Interestingly, Ball 2 was perceived as the softest and lightest, Ball 1 perceived as the heaviest and hardest, suggesting a potential relationship between the characteristics. Players were however unable to perceive differences with significance during the shooting exercise, potentially a result of fewer responses being collected during this exercise. Furthermore, this was believed to be a result of the repeatability of the shot technique, causing irregularities in the perceived feel of the ball off the foot, or potentially due to the sensitivity of the player during maximal effort shots or to small differences between the balls.

Direct objective measurements of the hardness and mass showed Ball 3 to be the hardest and lightest, Ball 2 the softest and heaviest. Average values of the quasi-static stiffness were calculated for a 2000 N compression and NCR values calculated from impact HSV footage. Ball 1 was the stiffest and deformed the least and Ball 2 was the most compliant and deformed the most under loading. Although the ordering of these two data sets were the inverse, the relative differences between the values were not directly comparable, which showed agreement with previous research that quasi-static stiffness values are not directly indicative of how a ball performs at high-speed impacts [10] due to the strain-rate dependence of the materials [11].

As shown in Figures 4 and 5, there was no immediate linear trend between perceptions of weight and hardness and objective measurements of these ball properties, suggesting that players’ perceptions of hardness and weight are not well interrelated with these properties. However, due to the small 8g difference in mass between the balls tested, further work considering the 40 g mass difference allowed by FIFA whilst limiting other ball variables is required to evaluate the extent of this. Measured Shore A hardness is limited to the outer material layers of the ball, and thus not representative of the complete ball product. Both the
quasi-static stiffness and high-speed impact NCR measurements share a trend with the passing subjective evaluation data, with the NCR measurements appearing to be more indicative of players’ perceptions of hardness and weight for the passing exercise. This is consistent with findings in tennis that showed a strong correlation between stiffness obtained through dynamic impact testing and players’ perception of hardness obtained during service and forehand shots [8]. Haake et al [10] and Collins [9] also suggested that ball dynamic stiffness has the closest physical property indicative of perception of hardness. This initial study has demonstrated some potentially indicative trends relating ball diameter normal compression ratio, quasi-static ball stiffness and players’ perceptions of hardness and weight, with direct measurement of ball mass and hardness appearing not to have a direct link to these players’ perceptions. Further work is required in order to evaluate the extent of these emerging trends and initial findings, which can be assessed by limiting variables between ball models such as stiffness, whilst systematically varying properties such as ball mass. The findings of this study are limited by the small subject number and sample size, which must also be addressed in order to determine the significance of these initial findings, as well as the inclusion of more in-play interactions to understand whether these findings are specific to the passing exercise.

5. Conclusion

The study was an initial investigation evaluating players’ perceptions of a football in respect to direct measurements of mass and hardness and objective measurements of ball deformation. A paired comparison method was used to compare footballs, whilst objective measurements were taken through a series of lab based tests. Analysis of the subjective paired comparison data showed that during the passing exercise players were able to perceive significant differences between the footballs in respect to hardness. The mass of the ball appeared to not share a direct linear relationship with perception of weight, likewise that measured Shore A hardness showed no linear trend with perception of hardness, suggesting a more complicated relationship than direct measurements for the balls tested. A trend has emerged between subjects’ perceptions and both quasi-static stiffness and dynamic impact diameter normal compression ratio with the dynamic impact diameter normal compression ratio data arguably showing the most promise as an indicator of players’ perceptions of hardness and weight.

Acknowledgements

The authors would like to thank adidas AG for their support in this project.

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