INTRODUCTION

Recent advances in wearable technology, in particular global positioning systems (GPS), enable measurement of athlete movement patterns and physical demands involved in sport [1]. Sports scientists and coaches, use this quantitative data to help establish the external loads of training and competition, in sports such as football [2]. Information obtained provide a detailed analysis of what each player has experienced during training and match play. This then allows Practitioners to tailor periodised training programs [3], which help to reduce the likelihood of injury [4,5] and attempt to optimise future performances [6,7]. Moreover, coaches are able to identify specific positional demands and individual performances and thus gain an advantage over their opponents as they are able to make tactical adjustments to compliment the physical characteristics identified [8]. Key metrics such as total distance covered, running at different speeds and distance covered are among the various types of activity measured [9]. There are many more including maximum speed achieved, distance covered walking, Jogging, Running, Sprinting and even positional mapping [10] and have now become the norm during training sessions and in match play [11,12].

Advances in technology has allowed these to become more accessible and has resulted in these becoming more common place in most professional and some non-professional teams. The wearing of devices to track player activity in football has recently been allowed under the rules of The Football Association [13], termed Elite Performance Tracking Systems (EPTS). These are worn by players in a suitably constructed top normally underneath their playing jersey in a purpose designed tight fitting vest ensuring stability of device in situ between the shoulder blades whilst enabling unrestricted movement of upper limbs and torso, that allows...
approved devices to be securely fitted [14]. As with other
team sports, football has adopted a standardised method
whereby these devices are placed in a pocket of a purpose
built garment that players wear, the device then sits on the
upper back between the shoulder blades (Figure 1). For the
use of any type of device in competitive match play they have
to be approved by sport governing bodies and referees hav-
ing the final say [14].

Football continues to increases in popularity, from 265
million participants in 2007 to more recent estimates of
over 500 million worldwide [15]. The UK alone has over 11
million registered participants [16] at various levels from
recreational to Elite level, this study also reported that the
largest number of participants take part at a recreational lev-
el. There has been a vast numbers of studies that have identi-
cified the physical demands imposed at the Elite 11 aside level
[17-20] yet there is still very little known in comparison to
other formats and levels across the participation landscape.
Small sided football is one of the most popular formats of
the game as it is employed across the football landscape [21].
Elite level teams use it as a tactical and physical conditioning
training tool and there is evidence that it is utilised at all
levels [22]. In a recent survey it was reported that there are
over 1.5 million adults participating in England each week
[23] and over 30,000 registered teams [16]. It is estimated
that number has increased due in part to the growth of nu-
merous facilities housing commercial leisure leagues. One
example of the many commercial enterprises promoting this
type of football in the UK has over 400 venues with in ex-
cess of 5,000 registered league teams and over 70,000 regular
users [24]. There has been some studies that have looked at
physical activity in non-elite football [15] these have been
more observational or involving laboratory type testing [25]
they do conclude that participation does improve health but
that more quantitative data is needed to better understand
the activities involved and the exact health benefits [26]. In
populations outside the elite environment, the use of weara-
table technology such as GPS has become popular with a vast
array of devices available. Many of these have been shown to
have little to no relevance, as they do not report accurately
on activity being recorded [27]. It has also been reported that
devices can over or underestimate on activity being tracked
[28]. This is mainly due to the quality of wearable technol-
ogy being used and what movements are being tracked [29].
Studies evaluating the use of wearable technology across all
users found that there are large discrepancies in the quali-
ity of data questioning the validity and reliability and this is
even found in elite athletic populations [30,31].

Similar technology to that within GPS tracking type de-
cives can be found in smartphones, a device which use is
now widespread with a reported 41 million of the UK pop-
ulation now using a smartphone [32]. With the development
of easily accessible applications, the use of smartphones for
these has grown. There is evidence emerging of elite pro-
fessional team sports such as football adopting the use of
smartphone applications, which are able to quantify power,
force and velocity in running and proven to be as reliable as
equipment used in a laboratory [33,34]. However, it should
be noted that this application evaluated in their study had
only been proven with one type of smartphone that being the
Apple IOS. Thus, it warrants further investigation to
evaluate other types of smartphones and applications to in-
clude Android as well as IOS. It has been reported [35] that
smartphone technology could be used to collect data effec-
tively in football such as distances and speeds. Although the
authors reported limitations in their study as they had no
comparison with other devices currently used. To the cur-
rent authors knowledge these have still not been assessed
across a range of smartphones with it being reported that
many only being tested on one device [36]. Added to this
many studies have questioned the validity and reliability
of various GPS tracking devices specifically in team sports
[28,37-39]. The purpose of this study is therefore to evaluate
a smartphone application installed on IOS and Android and
across a range of smartphones from Low to high end speci-
fication, for reliability and effectiveness in measuring physi-
cal activity. Added to this to also compare against a range of
GPS tracking type devices currently being used in football.

The aims of this study were; To validate the use of a range
of mobile device as a reliable method to gather physical data
and to compare against other tracking devices used in foot-
ball. Furthermore to evaluate use and comparison with oth-
er tracking devices in a football environment.

METHODS

Experimental approach to the problem

The study was designed in two parts, firstly to validate a
range of popular smartphones (Table 1) both Android and
Apple IOS type devices with an suitable application in-
stalled (PIN Services Ltd India) that tracks movement and
a range of GPS tracker type devices; Viper (Stat sports Ne-
wrn, Northern Ireland), Playertek (Catapult group Austra-
alia) Polar (Polar Electro Warwick, UK), Axsys (AxSyS per-
formance Canberra, Australia).These all to be transported
over a 20 meter shuttle course to a total distance 100 meter
to quantify total distance covered in meters, various speeds
in km/hr classified as walking ≤6.5km/hr, jogging ≥6.6km/
hr and an activity positional heat map (Figure 2). Secondly
a Smartphone and GPS tracker were tested in a small sided
football environment on all-weather 4th Generation astro turf playing surface small sided football Pitch measuring 36 × 27 meters boarded all round with a goal at each end. Results evaluated for comparison of common metrics used in football of total distance covered, various speeds, maximum speed reached and an activity positional heat map.

Subjects

Full time professional football players at a professional football club (n = 10, with a mean age 19 ± 1.8 years, height of 177 ± 6 cm, body mass of 77.6 ± 4.3 kg and estimated body fat percentage of 7.2 ± 1.2%) respectively participated in this study. Informed consent was provided by each player. Academic ethics approval was obtained even though the data was obtained from activities that players routinely undertook as part of the monitoring process during the course of the football season. This was to conform with parental consent which was also given for any player under the age of 18 years (n = 3). Participants completed a health screen questionnaire prior to the study, in addition each participant's capabilities to participate in physical activity was assessed by a Doctor and qualified Physiotherapist.

Experimental procedure

Part 1: Six mobile smartphones with the same application installed and 4 GPS tracking devices. On a clear sunny day on a hard standing area 2 cones were placed 20 meters apart. A subject carrying all in a purpose built aid that housed all devices, first walked between each cone 5 times turning at each cone 180°, travelling in total 100 meters. This was then repeated at a faster pace to replicate jogging, the test was then repeated on 2 more occasions and an average for each device over the 3 sessions was calculated. On completion of the test each smartphone and device had data collected which was then cropped in order to only collect data from when performing the test for later analysis (Table 2).

Part 2: 10 professional football players were grouped into 2 teams of 5 with each team defined by the wearing of a colour top for each team. A player was then selected from one of the teams to wear the GPS tracker unit with a smartphone in purpose built garment as used in previous tests (Figure 3). Each individual device was checked that switched on prior to start and remained on for the duration of testing. All participants were experienced in the wearing of the vests and units as they wear for all football training as well as Match play, player wearing the two devices did not complain of any issues nor did it impede in any way their normal range of movement or performance from the result of wearing of vests and fitted units. Play commenced in a 5v5 small-sided game format, 4 × 5 minute periods with 2 minutes rest between each period. As soon as the whole session was ended play stopped and data uploaded for analysis and presented. To ensure that just the in game data was collected for analysis, data was cropped so as to only use the actual in game data for each game of 5 minute periods (Figure 4). Data collected for analysis from both devices included: total distance covered measured in meters, Total distance covered at various speeds measured in metres, classified as walking ≤6km/hr, jogging 6.1-12km/hr, running 12.1-18km/hr, high speed running ≥18km/hr, maximum speed as km/hr (Table 3) and an activity positional heat map.

**Table 1. Smartphone brand, manufacturer and date of manufacture**

<table>
<thead>
<tr>
<th>Brand of smartphone</th>
<th>Manufacturer details</th>
<th>Year of manufacture</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTC ONE</td>
<td>HTC corporation Taiwan</td>
<td>2014</td>
</tr>
<tr>
<td>Iphone 5se</td>
<td>Apple inc USA</td>
<td>2017</td>
</tr>
<tr>
<td>Iphone 5</td>
<td>Apple inc USA</td>
<td>2016</td>
</tr>
<tr>
<td>Samsung Fame</td>
<td>Samsung Electronics South Korea</td>
<td>2013</td>
</tr>
<tr>
<td>Samsung Fame</td>
<td>Samsung Electronics South Korea</td>
<td>2015</td>
</tr>
<tr>
<td>Samsung Young 2</td>
<td>Samsung Electronics South Korea</td>
<td>2015</td>
</tr>
</tbody>
</table>
Table 2. Smartphone & GPS tracking device shuttle test Mean ± SD of total distance

<table>
<thead>
<tr>
<th>Device</th>
<th>Total distance (m)</th>
<th>Total distance walking (m)</th>
<th>Total distance jogging (m)</th>
<th>Max speed (km/hr)</th>
<th>Total distance (m)</th>
<th>Total distance walking (m)</th>
<th>Total distance jogging (m)</th>
<th>Max speed (km/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HTC one</td>
<td>98.0±3.4</td>
<td>72.5±5.5</td>
<td>24.8±5.3</td>
<td>6.7±0.3</td>
<td>99.8±2.2</td>
<td>7.8±2.6</td>
<td>45.7±10.6</td>
<td>46.2±8.8</td>
</tr>
<tr>
<td>Iphone 5 se</td>
<td>95.1±2.7</td>
<td>61.7±6.5</td>
<td>33.3±4.0</td>
<td>7.0±0.6</td>
<td>91.7±18.8</td>
<td>12.3±8.4</td>
<td>34.0±6.6</td>
<td>45.3±33.4</td>
</tr>
<tr>
<td>Iphone 5</td>
<td>96.7±2.3</td>
<td>54.3±13.2</td>
<td>41.7±10.6</td>
<td>6.9±1.0</td>
<td>100.7±3.8</td>
<td>9.7±5.5</td>
<td>53.0±22.1</td>
<td>38.3±30.1</td>
</tr>
<tr>
<td>Fame a</td>
<td>88.3±9.5</td>
<td>68.3±12.7</td>
<td>20.0±16.4</td>
<td>7.4±0.4</td>
<td>94.3±9.1</td>
<td>8.7±2.1</td>
<td>41.3±5.1</td>
<td>43.7±16.2</td>
</tr>
<tr>
<td>Fame b</td>
<td>88.0±7.6</td>
<td>60.3±15.9</td>
<td>28.0±16.1</td>
<td>6.7±0.8</td>
<td>94.7±8.9</td>
<td>8.3±1.5</td>
<td>39.7±2.2</td>
<td>47.0±28.6</td>
</tr>
<tr>
<td>Young 2</td>
<td>94.7±4.9</td>
<td>58.3±24.7</td>
<td>36.0±28.8</td>
<td>6.6±0.6</td>
<td>86.3±5.5</td>
<td>7.3±3.2</td>
<td>42.0±36.7</td>
<td>37.0±34.7</td>
</tr>
<tr>
<td>Polar</td>
<td>104.6±2.4</td>
<td>74.5±28.5</td>
<td>30.1±30.5</td>
<td>6.5±0.4</td>
<td>100.7±4.9</td>
<td>8.8±3.4</td>
<td>58.1±11.2</td>
<td>33.8±8.3</td>
</tr>
<tr>
<td>Viper</td>
<td>99.2±2.2</td>
<td>73.7±15.7</td>
<td>25.4±14.4</td>
<td>6.5±0.48</td>
<td>100.9±3.0</td>
<td>8.1±2.4</td>
<td>64.6±30.1</td>
<td>28.2±30.4</td>
</tr>
<tr>
<td>Playertek</td>
<td>97.0±3.5</td>
<td>N/A</td>
<td>N/A</td>
<td>6.4±0.7</td>
<td>97.0±3.5</td>
<td>N/A</td>
<td>N/A</td>
<td>13.8±0.8</td>
</tr>
<tr>
<td>assys</td>
<td>98.1±1.3</td>
<td>67.8±17.7</td>
<td>30.3±18.9</td>
<td>6.9±0.5</td>
<td>102.2±3.8</td>
<td>8.5±2.2</td>
<td>52.8±11.5</td>
<td>40.8±7.1</td>
</tr>
</tbody>
</table>

Table 3. GPS tracker device and smartphone tracking in 5 aside football match mean and SD over 4 games

<table>
<thead>
<tr>
<th>Device</th>
<th>Total distance (m)</th>
<th>Total distance walking (m)</th>
<th>Total distance jogging (m)</th>
<th>Max speed (km/hr)</th>
<th>Total distance (m)</th>
<th>Total distance walking (m)</th>
<th>Total distance jogging (m)</th>
<th>Max speed (km/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS Device</td>
<td>484.83±68.99</td>
<td>83.29±82.88</td>
<td>131.29±46.82</td>
<td>39.78±15.85</td>
<td>229.82±173.43</td>
<td>39.78±15.85</td>
<td>22.27±190</td>
<td></td>
</tr>
<tr>
<td>HTC one</td>
<td>476.88±54.12</td>
<td>100.33±90.61</td>
<td>159.25±65.99</td>
<td>15.05±13.17</td>
<td>202.25±170.95</td>
<td>15.05±13.17</td>
<td>23.34±191</td>
<td></td>
</tr>
</tbody>
</table>

Statistical analysis

Data are presented as mean ± SD, along with 95% confidence intervals (Table 4). First, to analyse the reliability of the smartphone app used for measuring the total distances and various speed zones employed, and to analyse with other types of smartphone coefficient of variation (%CV) were used. Secondly a repeated measures ANOVA was used to compare the smartphone app with GPS tracking device. Third to calculate the concurrent validity, the bivariate Pearson product moment correlation coefficient (r) was used. The Statistical Package for Social Science (SPSS, version 25) was used for all analysis.

RESULTS

There were no significant differences between types of smartphones in running (P<0.001; partial eta squared: 0) and high-speed running (P<0.001; partial eta squared: 0) distance, only small differences in walking (P=0.673; partial eta squared: 0.22) and jogging (P=0.578; partial eta squared: 0.26) distance and a small difference in total distance (P=0.328; partial eta squared: 0.35). Furthermore, only trivial differences in maximum speed were observed (P=0.934; partial eta squared: 0.11). Smartphone app and GPS tracking device showed a high degree of correlation (r = 0.94-0.99, P<0.001)

DISCUSSION

With ever-evolving smartphone applications and the increase in GPS tracking technology being used in sport, an analysis of a smartphone application and comparison with a range of GPS tracker devices currently used in sport was warranted.

The use of smartphone technology to measure physical activity is nothing new as there has been objective studies that support the use of in this way and reported that these were reliable and valid [40,41]. The major findings of this study support studies that reported that a smartphone application can reliably monitor physical activity [42,35]. This present study has gone further than previously published work in the area by assessing the validity and reliability across a range of smartphones, on what differences there are and comparison with a range of current GPS tracking devices used in sport and in a sport specific environment. However the current study does have limitations, only a small sample size of smartphones (n=6) were used in comparison, to the well over 100 different brands and types commercially available. Therefore a much larger study evaluating a greater number of smartphones would further the validity of wider use. A further potential limitation is that of the technology advancing at such a fast rate and the ability to objectively
evaluate the commercial claims made by manufacturers. Whilst the benefits allow for more advanced hardware and sensors [43,44,45], that are able to better report more types of physical activity in addition to those detailed within this present study. In keeping with results in previous studies [46], this present study found that GPS tracking type devices are a reliable and valid method in quantifying physical activity, but with varying levels of accuracy [47].

A current restriction is that of the rules for allowing their use in competitive match play, with a referee being the ultimate person responsible allowing these to be used or not. As with the GPS tracking devices currently being used in match play these had many barriers to overcome and are now widely accepted and allowed according to the rules of the game of football [13]. With the increase in affordability, GPS tracker devices and systems have become widely available and now used in the majority of training and match play within many football clubs [48]. As this is still a relatively new addition to the sport science toolbox within many football clubs, there warrants demand for further assessment on validity and reliability and is in line with studies that recommend further research [39]. Additionally, in any study comparing different types of technology across the football landscape, then measures of physical activity being reported need to accurately reflect those currently being performed [49]. By using the same software application for both GPS tracker device and smartphone allowed for consistency in the present study in the presentation of data resulting in better reliability [50] in reporting on the different speed zones when comparing GPS tracker device to smartphone.

Previous studies have highlighted significant differences across different methods and systems provided to track movement specifically in football [51]. With many of the metrics being reported differently by companies supplying these devices, specifically the variance in speed zones and this could explain why in the present study that there were such large differences when comparing Walking, jogging, running and High speed running across GPS tracker devices [1,28]. There was not so large a differences in the smartphones as they all had the same application installed and therefore all metrics were the same. There are challenges when conducting in depth analysis of commercial products in any area and GPS tracker devices are no different and whilst it is understandable that each varies their product to individualise in attempts to gain increase sales, for any researcher it is difficult especially as is in the present study where some metrics were not accessible (Table 2) and this has been reported in reviews of the literature [4,52,53]. This has caused much controversy in establishing reliability and validity in the use of GPS tracking devices in sport with both early studies [30] and more recent studies [54] continuing to highlight the need to set industry wide standards for the use in sport. Having the ability to easily monitor physical activity enables more people, some who maybe Fans of football to better connect to what their idols are doing and increase motivation to engage in physical activity related to football [55,56]. This increased motivation from engagement of fans in smartphone applications has been shown to have health benefits [57]. A further benefit is that with the capability to more accurately measure along with the capacity to report on more physical activity in diverse populations can help Health organisations and governing bodies to better understand participation [58] across the football landscape and thus inform solutions to benefits in health. By not having the need for additional technology, other than the installation of a suitable application, makes a compelling argument for the smartphone to be used as a reliable alternative to GPS tracker devices, that negates further costs to users.

**CONCLUSIONS**

The ability to readily monitor and evaluate physical activity is important in the areas of sport performance and health. This study shows that a range of smartphones with a suitably installed application, that physical activity can be reliably measured and applied to sport such as football. Also that it can be used to compare with other GPS tracking devices as used in sport. Having knowledge of the differences as described in this study enhances understanding and better equips participants and practitioners when evaluating performance and future needs. This in turn enables for better planning and the periodisation of training according to the individuals needs and requirements to be able to perform to maximise the benefits of the physical activity undertaking.

**ACKNOWLEDGEMENTS**

The authors would like to thank the participants and the undergraduate students who helped in data collection for this work.

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**Table 4. Differences for each variable including 95% confidence intervals**

<table>
<thead>
<tr>
<th></th>
<th>Mean Difference</th>
<th>Standard Deviation</th>
<th>Standard Error of the difference</th>
<th>95% Confidence Intervals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Distance (m)</td>
<td>8.0</td>
<td>17.1</td>
<td>9.8</td>
<td>-23.4, 39.3</td>
</tr>
<tr>
<td>Walking Distance (m)</td>
<td>-17.0</td>
<td>15.3</td>
<td>8.8</td>
<td>-45.1, 11.0</td>
</tr>
<tr>
<td>Jogging Distance (m)</td>
<td>-28.0</td>
<td>31.9</td>
<td>18.4</td>
<td>-89.5, 30.6</td>
</tr>
<tr>
<td>Running Distance (m)</td>
<td>27.6</td>
<td>42.0</td>
<td>24.3</td>
<td>-9.7, 104.8</td>
</tr>
<tr>
<td>HSR Distance (m)</td>
<td>24.7</td>
<td>5.3</td>
<td>3.1</td>
<td>14.9, 34.6</td>
</tr>
<tr>
<td>Max Speed (km×h⁻¹)</td>
<td>-1.1</td>
<td>0.4</td>
<td>0.3</td>
<td>-1.9, 0.3</td>
</tr>
</tbody>
</table>

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Conflicts of Interest

The authors declare no conflict of interest.

REFERENCES