A comparison between a new foot-mounted inertial measurement system and a local positioning system in amateur futsal

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Abstract

This study aimed to 1) establish the level of agreement between a foot-mounted inertial measurement system (PlayerMaker™) and a local positioning system (Catapult ClearSky™) for time-motion analysis variables in recreational futsal, (2) determine the level of agreement between the technical futsal performance variables of the foot-mounted inertial measurement units and video analysis (Catapult Vision), and 3) assess the match-to-match variability of the futsal players' physical and technical performances throughout recreational games of futsal. Twenty-eight male participants (mean ± SD age: 32.8 ± 11.7 years; stature: 179.6 ± 8.8 cm; mass: 83.4 ± 12.2 kg), each wearing a pair of PlayerMaker™ sensors and a Catapult ClearSky™ S7 Vector unit, played ten-minute games of five a side recreational futsal across the data collection period. The level of agreement for total distance covered (meters) between the PlayerMaker™ sensors (790 ± 107) and Catapult ClearSky™ (780 ± 104) was measured. The maximum velocity (meters per second) metric was quantified PlayerMaker™ (5.3 ± 0.6) and Catapult ClearSky™ (5.3 ± 0.7) to represent the level of agreement between the two systems. The level of agreement for the number of ball releases per futsal game was analysed in the present study between PlayerMaker™ (8.1 ± 5.9) and video analysis (16.1 ± 5.1). The level of agreement between PlayerMaker™ (18.5 ± 6.5) and video analysis (37.3 ± 5.3) for the number of ball touches per futsal game was also analysed. This study recommends the PlayerMaker™ inertial measurement system is utilised as a cheaper alternative to an LPS for quantifying time-motion analysis variables indoors. The PlayerMaker™ sensors might serve as a valid and reliable alternative to an LPS, but sporting practitioners must remain aware of the shortcomings of the system or of the various factors that compromise the quality of data produced by it.

1.0 Chapter 1: Introduction

1.1 Wearable Sports Performance Technology

The popularity of sport across the globe has provided an exponential growth in economic turnover within elite sports such as soccer (Sanchez, Barajas, & Sánchez-Fernández, 2019). The top division of professional English soccer (hereby known as football) sold their television broadcasting rights for 2.6 million pounds in 1983, but the rights were sold for 1,712 million pounds domestically in 2017 (Sanchez, Barajas, & Sánchez-Fernández, 2019). The financial wealth of the top division of English football has enabled its clubs to afford a wide range of the latest available technology (Kennedy & Kennedy, 2017). Therefore, the implementation and commercial availability of technology (multi-camera tracking systems, goal-line technology, electronic performance, and tracking systems etc) means technology is ever present in football (Hennessy & Jeffreys, 2018).

Wearable technologies are characterised as being small and lightweight measuring devices and are typically worn on or close to the body (Waldron, Harding, Barrett, & Gray, 2020). This anatomical placement of wearable technology varies from being housed between scapulae, mounted on the athlete's sporting footwear (Waldron, Harding, Barrett, & Gray, 2020), or within mouthguards (Bartsch & Samorezov, 2013). Wearable technologies are often utilised within sport to quantify objective athletic (e.g. total distance covered), technical (e.g. passes) or tactical (e.g. ball possession) performance data (Lutz, Memmert, Raabe, Dornberger, & Donath, 2020). Wearable technologies can provide sports scientists with an insight into the physical, physiological, and biomechanical capabilities of athletes as sports teams aim to increase their competitive success (Toner, 2023) by individualising training prescription (Pickering & Kiely, 2019).

The collection of data measured by wearable technology throughout sports performance are databased across multiple seasons in senior and academy sporting environments (Dawson, McErlain-Naylor, Devereux, & Beato, 2024). The wearable sports performance technology can provide valid and reliable measures of performance metrics such as total distance, total duration of physical activities, and heart rate zones (Pickering & Kiely, 2019), which have been shown to correlate with an athlete's physical and physiological readiness, and injury risk (Sands, Kavanaugh, Murray, McNeal, & Jemni, 2017). Therefore, the data quantified by wearable sports performance technology can inform sports practitioners (e.g. coaches, physios, sport scientists etc) across a sporting organisation on the demands of training and match-play (Torres-Ronda, Beanland, Whitehead, Sweeting, & Clubb, 2022). This is beneficial to every sporting organisation as the wearable sports performance technology data can provide them with an insight into each athlete's physical readiness in regards to the high intensity demands of sport and potentially prevent injury setbacks (Taberner, Allen, & Cohen, 2019).

1.2 Analysis of Physical Sports Performance Metrics

Physical sports performance (time-motion analysis) data is the quantification of the athletes' movements that they perform in training or match-play (Carling & Datson, 2023). To name just a few, time-motion analysis (external load) data metrics as quantified by wearable technology includes an athlete's distance covered, velocity, accelerations and decelerations in training and competition (Spyrou, Freitas, Marín-Cascales, Herrero-Carrasco, & Alcaraz, 2021). Time-motion analysis data can be quantified in real-time and or post physical activity (Rana & Mittal, 2020). Therefore, sports practitioners can use the time-motion analysis data to make instantaneous or retrospective decisions about each athlete's involvement throughout training and competition (Rana & Mittal, 2020). Typically, football time-motion analysis data is collected via the use of Global Positioning Systems (GPS) (Ehrmann, Duncan, Sindhusake, Franzsen, & Greene, 2016; Hennessy & Jeffreys, 2018; Ravé, Granacher, Boullosa, Hackney, & Zouhal, 2020) and to a lesser extent Local Positioning Systems (LPS) (Buchheit et al., 2014; Stevens, de Ruiter, Twisk, Savelsbergh, & Beek, 2017). The application of GPS and LPS are utilised to quantify physical sports performance data (Waqar, Ahmad, Habibi, Hart, & Phung, 2021).

GPS is a satellite-based navigation system incorporated of 27 satellites orbiting the globe (Larsson, 2003). A minimum of four satellites connections are necessary to triangulate the position of a GPS MEMS (micro-electromechanical system) device (Malone, Lovell, Varley, & Coutts, 2017). The GPS MEMS devices measure distance and velocity through positional differentiation (change of position from each signal) and doppler shift (measuring the change in frequency of each signal) respectively (Malone, Lovell, Varley, & Coutts, 2017). However, the use of GPS indoors is limited due to satellite signals being unable penetrate indoor sporting structures (Alarifi et al., 2016).

A local positioning system (Catapult ClearkSky™) quantifies physical performance data through the utilisation of antennae (transmitters) that surround sporting venues rather than a satellite network for using GPS (Alarifi et al., 2016). These antennae connect and communicate with the MEMS (receiver) devices using radiofrequency, infrared, ultra-sound, magnetic-technologies, vision-based technologies, or audible sound technologies (Alarifi et al., 2016). The athletes' MEMS devices are housed within tightly fitted, manufactured supplied vests that are worn throughout their sports performances (Waldron, Harding, Barrett, & Gray, 2020). The most commonly available LPS MEMS devices contain micro-sensors including (1) accelerometer (multi-axial movements); (2) magnetometer (device orientation direction); (3) gyroscope (angular rate and rotational velocity) to quantify the time-motion analysis data (Yazdi, Ayazi, & Najafi, 1998; Kunze, Bahle, Lukowicz, & Partridge, 2010).

Inertial measurement units (IMU) are another form of wearable technology used to quantify time-motion analysis data (Van der Kruk and Reijne, 2018). IMUs are also incorporated with 3D gyroscopes, 3D triaxial-accelerometers, and 3D magnetometers (Rana & Mittal, 2020). An inertial measurement system (PlayerMaker™) can quantify time-motion analysis data indoors and outdoors using a wireless Bluetooth connection, as they do not require satellite or antennae connection (Van der Kruk and Reijne, 2018). In addition, IMUs can measure an athlete's gait, which is the rhythmic alternating movement of an athlete's arms, legs, and trunk to create forward bodily movement

(Murray, 1967). These measures include step, stride, stance and swing length, and the orientation of body parts (Kawano et al., 2007; Fong & Chan, 2010). Gait symmetry is biomechanical characteristic derived from IMU gait analysis data (Wang, Sun, Li, & Liu, 2018). The IMU gait analysis data can reveal any biomechanical deficiencies such as gait asymmetry (Anwary, Yu, & Vassallo, 2018). The identification of biomechanical deficiencies are crucial as they can lead to hinderances in athletic performance or the development of injuries to the lower body due to the high-impact forces exerted whilst accelerating, running, decelerating, and changing direction (Young et al., 2022). Therefore, sporting practitioners can utilise the IMU gait analysis data and incorporate appropriate field and gym based exercises into each athlete's training programme with the aim of removing their specific deficiencies (Ross, Milian, Ferlic, Reed, & Lepley, 2022). However, IMUs have limited application for assessing and measuring technical performance metrics.

1.3 Analysis of Technical Sports Performance Metrics

The quantitative analysis of technical sports performance is typically carried out through the utilisation of video analysis coding software in conjunction with the video recording of the sports performance (Lord, Pyne, Welvaert, & Mara, 2020). Video analysis coding software permits sports practitioners to collect frequency data of technical sporting actions (e.g. shots, tackles, and passes etc) and review them with video clips (Lord, Pyne, Welvaert, & Mara, 2020). Each technical sporting action is identified using an agreed upon operational definition as a reference point for decision making (O'Donoghue & Hughes, 2019), which is necessary to provide the statistics with an increased degree of accuracy (Hughes, Franks, & Dancs, 2019). Multiple, well-trained sports video analysts are required to analyse the technical sporting actions and limit the variation in the video analysis data (Nevill, Atkinson, & Hughes, 2008). Sports video analysts must have a high degree of intra-coder reliability to show the consistency of an analyst's work (Choi, O'Donoghue, and Hughes, 2007). A high level of agreement (≥ 95%) between numerous skilled video analysts increases the inter-coder reliability of the frequency data (Nevill, Atkinson, Hughes, & Cooper, 2002).

However, the recent technological developments have seen the quantification of technical sports performance data be recorded by wearable technology (Emmonds et al., 2023; Losada-Benitez, Nuñez-Sánchez, & Barbero-Álvarez, 2023). These wearable IMUs can measure the time-motion analysis and technical performance data concurrently throughout football training and match-play (Losada-Benitez, Nuñez-Sánchez, & Barbero-Álvarez, 2023). Therefore, sports performance analysts in football can save time (Lewis 2022) and eliminate human error due the accuracy of the IMUs (Marris, Barrett, Abt, & Towlson, 2022). Whilst this nuance wearable technology is promising for quantifying technical football performance data due to acceptable concurrent validity (Waldron, Harding, Barrett, & Gray, 2020; Marris, Barrett, Abt, & Towlson, 2022; Myhill, Weaving, Barrett, King, & Emmonds, 2022), the current literature has not aimed to validate the wearable technology in any other codes of football. Since the creation of the Football Association in 1863, new versions of football have been created (Curry, 2023), such as Shrovetide, Gaelic, American football, rugby league, rugby union (MacKeddie-Haslam, 2022) and a South American indoor variant, futsal (Marques, Schubring, Barker-Ruchti, Nunomura, & Menezes, 2021).

1.4 Futsal

Futsal is an indoor form of football, played on a (40 x 20 meters) multi-use sports court (Castillo-Martinez et al., 2022), where each team aims to score goals by kicking the ball in the opposition team's goal net. An official game of futsal is played with five players per team (one goalkeeper and four outfield players), with a goal net (3 x 2 meters) at each end (Moore, Ramchandani, Bullough, Goldsmith, & Edmondson, 2018). A futsal squad is built up of 2 goalkeepers and 10 outfield players, who are utilised with a roll on roll off substitution system (Chen et al., 2022). A match has a scheduled duration of 40-minutes (2 x 20-minute halves) (Ahmed, Marcora, Dixon & Davison, 2020), however the clock is stopped when the futsal ball goes outside the dimensions of the court, therefore the matches last a duration of 75-90 minutes (Barbero Alvarez, Soto, & Barbero Alvarez, 2008). The futsal ball is one size smaller and heavier than a standard football (soccer-ball) (Widiyono, Setiandi & Susanto, 2022), causing the ball to only bounce once before being back in full contact with the playing surface (Gauthier & Tscholl, 2020).

Futsal was created in 1930 and is rapidly becoming the world's most popular indoor sport (Fitri et al., 2021). The dynamic and fast-paced nature of the sport, comprising of short and explosive movements, makes futsal a physically demanding sport (Naser, Ali, & Macadam, 2017). The physical demands of futsal are combined with a balance of technical foot-based skills and tactical interchange of positions (Ribeiro et al., 2022). Futsal could function as a donor sport for football at a professional level (Travassos, Araújo, & Davids, 2018) as footballing icons including Ronaldo Nazario and Ronaldinho played futsal throughout their youth (Hermans & Engler, 2010). In South America, aspiring footballers have made the switch to futsal if they have been unable to gain success in professional football (De Oliveira, 2020). The popularity of futsal influenced global broadcasters to invest in futsal and broadcast the sport on UK television (BT Sport, 2021). Although the main aim of this research is to assess the concurrent validity between Catapult ClearSky™ and PlayerMaker™, this research could contribute to the wider futsal community with the assessment of the physical demands of amateur futsal. Therefore, the physical demands of futsal match-play could be compared across multiple levels of competition. The concurrent validity of PlayerMaker™ and Catapult ClearSky™ could be financially beneficial to indoor sports such as basketball or netball, which have previously utilised Catapult ClearSky™ to quantify time-motion analysis data (Benson, Brooks, Bruce, & Fox, 2020a; Russell, McLean, Stolp, Strack, & Coutts, 2021). This would provide basketball and netball teams with an externally valid and financially viable wearable technology system for measuring athletes' time-motion analysis data.

1.5 Research Aims

In the absence of criterion measures for both LPS and FIMUs, the aims of the study were to: (1) establish the level of agreement between a foot-mounted inertial measurement system (PlayerMaker™) and a local positioning system (Catapult ClearSky™) for time-motion analysis variables in recreational futsal, (2) determine the level of agreement between the technical futsal performance variables of the foot-mounted inertial measurement units and video analysis (Catapult Vision). The final aim of this research was to (3) assess the match-to-match variability of the futsal players' physical and technical performances throughout the ten-minute games of futsal played throughout the data collection sessions.

1.6 Hypothesis

We hypothesised that there would be good – excellent levels of agreement between PlayerMaker™ and Catapult ClearSky™ for quantifying distance covered. However, we expected that the FIMUs would measure greater total distance than the LPS and the LPS would record a greater maximum velocity than the FIMUs. We hypothesised that the FIMUs and notational video analysis would have a high level of agreement. Finally, we hypothesised that there would be worthwhile changes to the time-motion analysis and technical performance data within the match-to-match variation section of the present study.

2.0 Chapter 2: Literature Review

2.1 Time-Motion Analysis Data

Although physical sports performance monitoring technology results in a substantial financial cost (Kos, Wei, Tomažič, & Umek, 2018), the quantification of physical sports performance data can aid the identification of the athletes' physical capabilities (Scott, Scott, & Kelly, 2016). Strength and conditioning coaches prescribe training programmes based on the athlete's individual physical performance data to develop the athletes' physical "strengths" and "weaknesses" (Scott, Scott, & Kelly, 2016). Therefore, each athlete's levels of physical sports performance can be improved through a gradual increase in load, if the athletes are to meet and or exceed the physical requirements of their sport (Bompa & Buzzichelli, 2021). It is considered good practice for the external load of sports training to be planned, programmed, and periodised, so the athletes can meet their positional demands of sporting competition (Campbell, Bove, Ward, Vargas, & Dolan, 2017). Further considerations for the measurement of external load could be due to a congested competitive fixture schedule, with potential injuries tending to occur in weeks where there are multiple fixtures (Carling, McCall, Le Gall, & Dupont, 2016).

However, sporting practitioners must be aware of fine balance when gradually increasing load between preparing athletes to achieve their physical demands of their sport and reducing the risk of potential injuries occurring to the athlete's soft tissue (Guitart et al., 2022). External load metrics such as total and relative distance covered, maximum velocity, distances across velocity thresholds, accelerations and decelerations (Carling & Bloomfield, 2013) are viewed as predictive measures for analysing athletes' risk of potential injuries (Akenhead & Nassis, 2016). The importance of monitoring athletes' external load throughout training and match-play is reinforced as athletes are more likely to suffer injuries during sports performance due to significant increases in external load variables (Martins et al., 2023).

Despite literature stating that athletes are at an increased risk of potential injuries (overuse) occurring during sports performance if their acute workload (7 days) ratio exceeds (>1.5) their chronic workload (3 to 6 weeks) (Gabbett, 2016), there is literature which does not believe that the acute chronic workload ratio (ACWR) is relevant to the injuries sustained by athletes (Impellizzeri, Tenan, Kempton, Novak, & Coutts, 2020). The ACWR is viewed as an inaccurate method that does not link training load to injury due to its lack of conceptional basis and inconsistent results (Impellizzeri, Tenan, Kempton, Novak, & Coutts, 2020). Impellizzeri, Tenan, Kempton, Novak, and Coutts (2020) do not recommend the use of the ACWR in sporting practice as inappropriate training loads would be recommended by sporting practitioners to the coaches and performance staff. This could lead to the athletes being physically underprepared due to a lack of exposure to appropriate training loads (Impellizzeri, Tenan, Kempton, Novak, & Coutts, 2020).

Total Distance

Total distance (TD) covered (meters) is the accumulation of how far an athlete has moved throughout physical activity (Catapult, 2022). The TD metric is one of the most established physical performance metrics, which is quantified by wearable technology through positional differentiation (distance over time) (Cardinale & Varley, 2017). The monitoring of athlete's TD is paramount for optimising physical performance as sports practitioners attempt to prevent overuse, stress, and strain injuries from occurring (Gabbett, 2020). Previous research has shown that a 15% or greater increase in training volume from the previous week amplified the risk of potential injuries between 21-49% (Gabbett, 2016). Therefore, sporting practitioners must manage each athlete's TD throughout training and match-play to maintain optimal performance levels and prevent athletes sustaining potential musculoskeletal injuries (Kalkhoven, Watsford, Coutts, Edwards, & Impellizzeri, 2021).

TD is a key performance metric in futsal as elite outfield futsal players cover an average of 3749m in a 40-minute game (Ribeiro et al., 2020). By contrast, other research within elite futsal has observed an average TD of 3375m (Serrano et al., 2020). According to Barbero Alvarez, Soto, and Barbero Alvarez (2008) the unlimited substitution system decreases the importance of the TD covered data metric for futsal. Previous research in futsal has revealed that a futsal player's TD covered increases within the second half of futsal games by 4% because of the unlimited substitutions and additional time on the futsal court (Barbero Alvarez, Soto, & Barbero Alvarez, 2008). Recent research found that the average TD covered by futsal players was 6% lower in the second half compared to the first (Ribeiro et al., 2020). Futsal (outfield) players averaged a total distance of ~2000 meters in first halves of futsal matches (Ribeiro et al., 2020), causing athletes fatigue levels to be increased going into the second (20-minutes) halves of matches (Spyrou, Freitas, Marín-Cascales, & Alcaraz, 2020). The TD metric provided by the PlayerMaker™ FIMUs would allow for a greater understanding of the external load of futsal match-play (Spyrou, Freitas, Marín-Cascales, Herrero-Carrasco, & Alcaraz, 2022).

Relative Distance

Relative (average) distance (RD) quantifies an athlete's work rate as it is the amount of distance covered per minute (m/min) throughout physical activity (Dal Pupo, Barth, Moura, & Detanico, 2020). Ribeiro et al (2020) identified RD as one of the key performance metrics related to the physical demands of futsal performance because RD is a measure of intensity for the total amount of time an athlete has played (Cummins, Orr, O'Connor, & West, 2013). Futsal players RD covered decreased by 7% (Barbero Alvarez, Soto, & Barbero Alvarez, 2008). The decrease in second half RD could be due to the high number of anaerobic efforts within futsal, resulting in the athletes suffering from muscular and neuromuscular fatigue (Dogramaci & Watsford, 2006). On the other hand, recent research (Ribeiro et al., 2020) quantified elite futsal players RD at 232 meters per minute in a full match. There was also an increase in RD throughout the second halves of futsal matches within the aforementioned study, which was twice the amount of previous futsal research (Barbero-Alvarez, Soto, Barbero-

Alvarez, & Granda-Vera, 2008; De Oliveira Bueno et al., 2014; Dogramaci, Watsford, & Murphy, 2015). This increase is potentially related to futsal as teams have the ability to substitute their entire team at any time. Further research (Serrano et al., 2020) observed no differences between the RD between both halves of futsal match-play. The futsal wingers were found to be the only futsal position where there was a decrease in the RD during the second halves of match-play (Serrano et al., 2020). Consequently, relative time-motion analysis data is more appropriate for analysing the physical demands of futsal, rather than absolute (total) time-motion analysis data due to the unlimited substitution rules in futsal (Serrano et al., 2020). The PlayerMaker™ FIMUs would increase sporting practitioners' understanding of the intensity of futsal match-play and the work rate futsal players must sustain throughout match-play (Barbero-Alvarez, Soto, Barbero-Alvarez, & Granda-Vera, 2008). Hence, the relative distance data from the PlayerMaker™ FIMUs could be utilised to apply the appropriate types of training (circuit & interval) and conditioning to futsal players, so they can meet the intensity demands of match-play (Taufik, Setiakarnawijaya, & Dlis, 2021).

Velocity Thresholds

As a result of the highly intermittent aspects of futsal, futsal players cover distances throughout training and match-play at various running velocities (Castagna, D'Ottavio, Vera, & Álvarez, 2009). The lower velocity thresholds categorises futsal players movements into absolute (grouped) velocity thresholds for walking (≤ 1.67 m/s), low-speed running (1.68 – 3.33 m/s), medium-speed running (3.34 – 4.28 m/s) (Castagna, D'Ottavio, Vera, & Álvarez, 2009). Castagna, D'Ottavio, Vera, and Álvarez's (2009) research showed ~32% of TD covered is walking, ~42% is low-speed running, and ~30% is medium-speed running. However, Ribeiro et al. (2020) observed an average walking distance (≤ 1.67 m/s) (WD) of 1645m throughout professional futsal match-play. Whereas professional futsal players covered an average of 1322 low-speed running meters (1.68 – 3.3 m/s) per 40-minute match (Ribeiro et al., 2020). This is potentially because futsal players require 20-30 seconds at slower velocities to recover from high-speed efforts (Castagna, D'Ottavio, Vera, & Álvarez, 2009).As previous research has been based in professional futsal (Castagna, D'Ottavio, Vera, & Álvarez, 2009; Ribeiro et al., 2020), amateur futsal players require lower velocity thresholds due to their reduced physical capabilities in comparison with professional futsal players (Naser & Ali, 2016). As such, the distances covered in various velocity thresholds, measured by the PlayerMaker™ FIMUs, can reveal the percentage and or average amount of walking, jogging, and running required at the different levels of futsal competition (Mohammed, Shafizadeh, & Platt, 2014).The PlayerMaker™ FIMUs can set up the velocity thresholds of futsal players to be either grouped or individualised as the amount of walking, jogging, and running performed during match-play is futsal position dependent (Iedynak et al., 2019).

Although the current study and previous research within futsal have seen absolute velocity thresholds used (Castagna, D'Ottavio, Vera, & Álvarez, 2009; Ribeiro et al., 2020), the individualisation of velocity thresholds in team sports can reduce the drawbacks of grouped velocity thresholds (Scott & Lovell, 2018). These individualised velocity thresholds have previously been based on Maximal Aerobic Speed (MAS) (Bradley & Vescovi, 2015), Anaerobic Speed Reserve (ASR) (Palucci Vieira, Carling, Barbieri, Aquino, & Santiago, 2019), and Maximum Sprint Speed (MSS) (Buchheit, 2010). MAS is an individual's lowest running velocity at which VO^2 Max occurs and can be calculated through a series of laboratory or field-based tests (e.g., treadmill test, 5-minute run etc.) (Ferretti, 2015). Whereas ASR is the difference between MAS and MSS (Buchheit & Laursen, 2013). Individualised high-speed running (speed over MAS) and sprinting (50% of ASR) thresholds are calculated using MAS and MSS (Mendez-Villanueva, Buchheit, Simpson, Bourdon, 2013). An athlete's MAS will decrease unless they are provided with the appropriate conditioning throughout a pre-season and during the competitive season (Kalapotharakos, Ziogas, & Tokmakidis, 2011). Even though the individualisation of velocity thresholds can estimate each athlete's physical fitness, absolute thresholds can simplify the data collection process and coaches can set a basis for their athletes (Clemente et al., 2023). Furthermore, the tests conducted to individualise someone's velocity thresholds can be time-consuming, expensive, and require the appropriate facilities and equipment (Lovell & Abt, 2013).

High-Speed Distance

High-speed running distance (HSD) covered has been previously set to absolute velocity thresholds (e.g. 5.5 – 7 meters per second (m/s)) (Suárez-Arrones, Portillo, González-Ravé, Muñoz, & Sanchez, 2012) or set up as a percentage of an athlete's individual maximum sprinting velocity (≥ 65%) (Reardon, Tobin, & Delahunt, 2015). However, sporting organisations with access to the resources and personnel to individualise high speed running (HSR) thresholds based on MAS are recommended to do so because of each person's differing physical capabilities (Abt & Lovell, 2009). Sporting practitioners perceive HSD as key time-motion analysis variable due to high-speed movements being the most strenuous for athletes and increases the risk of potential lower limb injuries (Cardinale & Varley, 2017). For instance, a sudden surge in the HSD covered by athletes exposes them to an increased risk of hamstring and calf muscles (gastrocnemius & soleus) strains (Duhig et al., 2016). HSD can lead to injuries to the hamstrings because they have to absorb greater forces the faster an athlete runs (Wolski, Pappas, Hiller, Halaki, & Fong Yan, 2024). Whereas injuries to the calf muscles can occur during HSR due to the higher forces generated and absorbed by the calves when pushing off and landing (Green et al., 2019). The hamstrings and calf muscles may not be capable of repeating these actions at a high intensity if athletes have not had enough exposure to HSD conditioning or the muscles stretch or contract too quickly (Wilson, Czubacka, & Greig, 2020; Robinson, & McInnis, 2021). However, exposing athletes to an appropriate volume of HSR within their total distance covered and intensity of HSD covered (HSD per minute) in training and during return to play protocols will prepare athletes for the high intensity demands of their sport (Reid, Cowman, Green, & Coughlan, 2013; Ruddy et al., 2018).

HSD covered has been quantified in futsal when the players achieve a velocity of ≥ 4 m/s throughout training or match-play (Barbero Alvarez & Castagna, 2007; Barbero-Alvarez, Soto, Barbero-Alvarez, & Granda-Vera, 2008; Serrano et al., 2020). The HSD velocity threshold within futsal differs from the 5.5 – 7 m/s velocity threshold due to the dimensions of a futsal court limiting the space futsal players have to achieve higher velocity thresholds (Caetano, Bueno, Marche, Nakamura, Cunha, & Moura, 2015). The percentage of TD covered at high-speeds withing professional futsal is 13.7%, with a high-intensity action performed on average every 43 seconds (Barbero Alvarez & Castagna, 2007; Barbero-Alvarez, Soto, Barbero-Alvarez, & Granda-Vera, 2008). For example, De Oliveira Bueno et al. (2014) measured a decrease in HSD within the second half (9.6%) of professional futsal matches, whilst the ball was in-play, compared to first half (10.3%). Although the relative HSD in both halves of professional futsal matches ranged from ~12-18 HSD m/min, there was no difference from the first half to the second half in relative HSD (De Oliveira Bueno et al., 2014). HSD is greater in futsal compared to football because of the smaller playing area and reduced number of players on each team (Milanović, Sporiš, Trajković, & Fiorentini, 2011). The high anaerobic and aerobic capacity levels of futsal players, as well as the unlimited substitution rules of futsal, means that futsal players can achieve HSD covered in a futsal match (Serrano et al., 2020). The PlayerMaker™ FIMUs ability to quantify the total HSD covered and relative HSD covered in futsal match-play. This would enhance sporting practitioners' understanding of futsal as it would reveal what the high-speed demands of amateur futsal match-play are compared to professional futsal (Barbero-Alvarez, Soto, Barbero-Alvarez, & Granda-Vera, 2008). Futsal practitioners would be able to plan and recommend an appropriate HSR load target for training based on the HSR data measured by the PlayerMaker™ FIMUs throughout match-play and minimise the risk of potential lower limb injuries (Beato, Coratella, Schena, & Hulton, 2017).

Sprint Distance

Sprint distance (SD) requires futsal players to reach a velocity ≥ 5 m/s, and a sprint must be greater than the velocity threshold for ≥ 10m to be registered by the GPS MEMS device or IMU (Serrano et al., 2020). Sprinting has been identified as a substantial cause for the onset of neuromuscular fatigue (NMF) (Milioni et al., 2016), where muscle groups are unable to generate maximal force due to rigorous physical activity (Assmussen, 1979). The repeated sprints performed in futsal match-play means that players require a high neuromuscular capacity to delay the onset of NMF (Spyrou, Freitas, Marín-Cascales, Herrero-Carrasco, & Alcaraz, 2021). Research in professional futsal has observed 92% of injuries occurring to futsal players lower limbs because of the high number of sprints and high-intensity efforts (López-Segovia, Fernández, Carrasco, & Blanco, 2022). Previous research indicates that futsal players cover ~130m whilst sprinting during futsal match-play (Naser, Ali, & Macadam, 2017). In contrast, Serrano et al. (2020) found that 8.9%-10.1% of futsal players TD in match-play was SD. Serrano et al. (2020) findings showed that futsal players sprint every 56 seconds on average throughout match-play. Therefore, the ability to repeatedly sprint throughout futsal matches means that the athletes require both a high aerobic and anaerobic capacity (Naser, Ali, & Macadam, 2017).

The PlayerMaker™ FIMUs' capacity to qualify sprints and sprinting distance would be beneficial to futsal as wearable technology provides an insight into the sprinting demands of match-play and training (Ribeiro et al., 2020). The insight into futsal sprinting can be used by futsal practitioners to optimise physical futsal performance (Spyrou, Freitas, Marín-Cascales, & Alcaraz, 2020). Futsal practitioners can tailor the sprint based conditioning within training based on the demands of futsal match-play to help futsal players cope with the repetitive sprinting demands within futsal and prevent potential injuries to the hamstring, calf, and groin muscles (Ribeiro et al., 2020). Frequent sprint exposure can supply the fast twitch muscle fibers with enough of a stimulus to potentially prevent soft tissue injuries (Gabbett & Oetter, 2024). However, tendon injuries or tightness may occur as a response to acute sprinting load due to the structure of tendons being altered for two days after sprinting (Docking, Daffy, Van Schie, & Cook, 2012).

The relationship between inadequate and excessive sprint exposure in terms of injury prevention is complex (Gabbett & Oetter, 2024). A lack of sprint exposure does not provide enough stimulus to the anerobic energy systems or activation of the fast twitch muscle fibers (Plotkin, Roberts, Haun, & Schoenfeld, 2021). Whereas excessive sprint exposure causes extreme stress on the soft-tissue and a recommendation of 48-72 hours for recovery before sprinting again (Haugen, Seiler, Sandbakk, & Tønnessen, 2019). This relationship is also affected by the physical capabilities of the athletes (power and strength) that sporting practitioners attempt to enhance in the gym and provide a stimulus to the muscles required for sprinting (Gabbett & Oetter, 2024). .

Maximum Velocity

Maximum velocity (m/s) is an athlete's top speed and is quantified by the wearable measuring devices with through the doppler shift for the greatest level of speed accuracy (Malone, Lovell, Varley, Coutts, 2017). Maximum velocity is calculated by GPS MEMS devices using the doppler shift, which measures the change in frequency of the satellite signals (Malone, Lovell, Varley, Coutts, 2017). Whereas, LPS MEMS devices quantify maximum velocity via positional differentiation (Catapult Sports, 2022). The accuracy of the maximum velocity data provided by the wearable measuring devices could be potentially increased if the sampling frequency of the wearable measuring devices is greater (Malone, Lovell, Varley, Coutts, 2017). Maximum velocity is an important time-motion analysis variable as sports practitioners can select a percentage of the athlete's top speeds for them to run at, if they are rehabilitating athletes back from injury (Windt & Gabbett, 2017). Buchheit, Settembre, Hader, and McHugh (2023) observed no hamstring injuries in football match-play when footballers were exposed to ≥ 95% of their maximum velocity within training two days prior to competition.

The quantified top speeds of elite futsal players range from 5.5–6.2 m/s (Ribeiro et al., 2020). Ribeiro et al. (2020) identified no significant difference between the three different outfield futsal playing position's top speeds, with each position having an average top speed of ~5.5 m/s. Although there are several positional rotations throughout futsal match-play, outfield futsal playing positions consist of wingers, defenders, and pivots (Serrano et al., 2020). Futsal wingers average a top speed of 5.8 m/s, which is greater than the defenders (5.6 m/s) and pivots (5.7 m/s) top speeds (Serrano et al., 2020). Serrano et al. (2020) observed no differences between the top speeds of the professional futsal players within each half of match-play. Previous research emphasises the importance and development of top speed for futsal players to compete in elite futsal (Spyrou et al., 2020). The increase in the top speeds achieved by futsal players in recent years could be due to the increased physical demands of futsal (Ribeiro et al., 2020). The PlayerMaker™ FIMUs maximum velocity data could increase sporting practitioners' knowledge on futsal as it reveals the top speeds of the wearers in training, match-play, and fitness testing (Waldron, Harding, Barrett, & Gray, 2020). Accordingly, futsal practitioners will understand the top speed percentages that futsal players will need to achieve in training and prior to competition. It has been revealed that footballers will have the risk of hamstring strains reduced during match-play if they reach a speed that is ≥ 95% of their top speed two days prior to competition (Buchheit, Settembre, Hader, and McHugh, 2023).

Acceleration and Deceleration

Acceleration is defined as the rate at which someone changes their velocity and deceleration is the process of decreasing velocity (Delves, Aughey, Ball, & Duthie, 2021). Despite accelerations and decelerations being some of the most important metrics to monitor in futsal (Ribeiro et al., 2020), the disparity between the Catapult ClearSky™ LPS and the PlayerMaker™ FIMUs for quantifying accelerations and decelerations meant the level of agreement between these time-motion analysis could not be analysed in the present study. The ability to accelerate and decelerate is crucial to futsal and football as the players must perform technical actions (dribbling and tackling) in small spaces with and without the ball (Arruda et al., 2015). The number, distance and speed of the accelerations and decelerations performed by athletes in sport are important due to the high amounts of load that changes in velocity have on athlete's lower body extremities (Harper, Carling, & Kiely, 2019). Therefore, accelerations and decelerations may need to be monitored by sporting practitioners to prepare athletes for the physical demands of their sport and lower the chances of potential injuries occurring (Zadeh et al., 2021). Wearable sports performance measuring devices quantify accelerations and decelerations through the use of the sensors and accelerometers embedded in the MEMS devices (Catapult Sports, 2022).

Previous research in elite futsal match-play quantified the number of accelerations and decelerations (Serrano et al., 2020; Ribeiro et al., 2020). Serrano et al. (2020) also identified that elite futsal players perform 7.4–9.4 accelerations and 7.4–9.1 decelerations per minute. Whereas Ribeiro et al. (2020) observed 5 accelerations and decelerations per minute in elite futsal. Although Serrano et al. (2020) observed no significant differences in the number of accelerations and decelerations based on futsal playing position, futsal defenders recorded the highest average number of accelerations (9.4 per minute) and decelerations (9.1 per minute). However, Ribeiro et al. (2020) did not compare the number of accelerations and decelerations in each futsal position. There was also a slight decrease in the number of second half accelerations and decelerations completed by futsal wingers and defenders compared to the first halves of match-play. In contrast, the elite futsal players in the Ribeiro et al. (2020) study showed that there was no decrease in accelerations and decelerations per minute across both halves of futsal match-play. However, the number of accelerations and decelerations per minute in the Ribeiro et al. (2020) study could have differed with further investigation into futsal playing positions (Illa, Fernandez, Reche, & Serpiello, 2021). Accelerations and decelerations could have potentially decreased in the second halves of elite futsal match-play (Serrano et al., 2020) because of neuromuscular fatigue onset by the higher average amount of playing area to cover (Harper, Carling, & Kiely, 2019; Spyrou, Freitas, Marín-Cascales, & Alcaraz, 2020).

The accelerations (2-3 m/s^2; 3-4 m/s^2; 4-5 m/s^2; 5-6 m/s^2) and decelerations (3-2 m/s^2; 4-3 m/s^2; 5-4 m/s^2; 6-5 m/s^2) per minute were also quantified across velocity zones (Serrano et al., 2020). The acceleration threshold with the most accelerations in throughout elite futsal match-play was 4-5 m/s^2 (Zone 3) with futsal players performing ~6 accelerations per minute (Serrano et al., 2020). Elite futsal players were measured to decelerate ~5-6 times per minute in deceleration zone 3 (5-4 m/s^2), which was the threshold that had the most decelerations measured in throughout elite futsal (Serrano et al., 2020). The most accelerations and decelerations that occurred in the higher thresholds could have been due to the elevated intensity and physical demands of professional futsal match-play compared to the lower levels of futsal competition (Barbero Alvarez & Castagna, 2007).

2.2 Local Positioning System (LPS) Technology

Catapult ClearSky™ (Catapult Sports, Melbourne, Australia) is a local positioning system designed to quantify physical sports performance (e.g. distance, velocity, accelerations, decelerations, and PlayerLoad), in both an indoor and outdoor environment. The use of LPS technology can quantify physical performance data through pre-installed anchor nodes (antennae) that surround a sporting venue or a portable receiver for an outdoor sporting environment (Catapult Sports, Melbourne, Australia). The anchor nodes communicate with the measuring devices, worn by the athletes, on an ultra-wide band (UWB) radio frequency allowing for time-motion analysis (physical performance) data to be quantified (Catapult Sports, Melbourne, Australia). The anchors receive the athlete's movement data through the air because of the radio waves emitted from the measuring devices (Catapult Sports, Melbourne, Australia). The use of UWB technology benefits the collection of athlete external load data due to its capabilities to penetrate objects indoors, whilst maintaining the same data collection rate because of the low frequency pulses (Miller, 2003).

Even though Catapult ClearSky™ has been widely applied across sports performance, the UWB frequency that Catapult ClearSky™ utilises to quantify has drawbacks that can reduce the accuracy of the time-motion analysis data such as signal noise and multipath propagation (Alarifi et al., 2016). Noise in measurement systems refers to undesired alterations to the signals when time-motion data is being quantified (Mohd-Yasin, Nagel, & Korman, 2009). Signal noise reduces the accuracy of the time-motion analysis data unless strategies are implemented to reduce the impact of noise, such as signal processing techniques or advanced algorithms (Han, Meng, Omisore, Akinyemi, & Yan, 2020). Noise can occur within UWB technology due to electronic interference such as wireless communication networks or devices that emit electromagnetic waves, causing the frequencies to overlap (Brunner, Stocker, Schuh, Schuß, Boano, & Römer, 2022). Noise within MEMS technology could also occur due to intrinsic issues such as mechanic-vibration noise and thermal noise from within the device (Tanner et al., 1999). Whereas multipath propagation refers to the signals taking multiple paths to reach the receiver (Sathyan, Shuttleworth, Hedley, & Davids, 2012). Multipath propagation occurs due to the signals being reflected off walls and other objects (Sathyan, Shuttleworth, Hedley, & Davids, 2012). This can decrease the accuracy of the time-motion analysis data as reflected signals could contain more noise in comparison to signals that take a direct path (Sathyan, Shuttleworth, Hedley, & Davids, 2012). However, the large bandwidth (range of frequencies) of an UWB LPS reduces the effects of multipath propagation as the system would be able to differentiate between direct and reflected signals (Alarifi et al, 2016).

Inter and Intra-Device Reliability of LPS Technology

The inter-device reliability of MEMS devices is known as between-device reliability (Crang, Duthie, Cole, Weakley, Hewitt, & Johnston, 2021). The assessment of an LPS system's inter-device reliability is key when quantifying the data of multiple athletes (Crang et al., 2021). This is imperative because inter-device variability can decrease the accuracy of the time-motion analysis data (Bastida-Castillo, Gómez-Carmona, De La Cruz Sánchez, & Pino-Ortega, 2019a). As there is no research that has been made available on the reliability of Catapult ClearSky™ (Müller, Willberg, Reichert, & Zentgraf, 2022), it is recommend that participants wear the same LPS MEMS device to reduce inter-device variability (Bastida-Castillo et al., 2019b). Previous literature on LPS technology provides limited inter-device variation for distance and velocity parameters (Hoppe, Baumgart, Polglaze, & Freiwald, 2018; Rico-González, Los Arcos, Clemente, Rojas-Valverde, & Pino-Ortega, 2020).

Whereas intra-device reliability (test-retest) is referred to as within-device reliability (Nicolella, Torres-Ronda, Saylor, & Schelling, 2018). Intra-device reliability is beneficial to sporting practitioners when analysing time-motion analysis data across a period of time to observe any improvements or deteriorations (Crang et al., 2021). As true intra-device reliability is difficult to determine due to the human factors (Crang et al., 2021), the number of LPSs that have had their intra-device reliability assessed are limited (Leser, Schleindlhuber, Lyons, & Baca, 2014; Rhodes, Mason, Perrat, Smith, & Goosey-Tolfrey, 2014; Bastida Castillo, Gómez Carmona, De la Cruz Sánchez, & Pino Ortega, 2018). Despite no research being available on the reliability of Catapult ClearSky™, it was determined that the intra-device reliability of an UWB LPS was acceptable for measuring time-motion analysis variables (Bastida Castillo, Gómez Carmona, De la Cruz Sánchez, & Pino Ortega, 2018).

Application and Attempted Validation of LPS Technology

The application of the LPS has been used to quantify the training and competitive demands of indoor sports including handball, elite level basketball, and netball (Serpiello et al., 2017; Luteberget, Spencer, & Gilgien, 2018; Brooks, Benson, Fox, & Bruce, 2020a; Russell, McLean, Stolp, Strack, & Coutts, 2021). Brooks, Benson, Fox, and Bruce (2020a) applied the use of the LPS to quantify the physical demands of elite-level netball, including distance, velocity, accelerations, and PlayerLoad. In contrast, Luteberget, Spencer, and Gilgien (2018) attempted to validate the instantaneous velocities and distance covered parameters quantified by Catapult ClearSky™ against an infrared light-based camera system (Qualisys Oqus, Qualisys AB, Sweden) with handball players as the participants. Similarly, Serpiello and colleagues (2017) assessed the validity of the distance, velocity, acceleration, and deceleration variables calculated by Catapult ClearSky™ against a 12-camera Vicon™ motion analysis system (criterion system). Whereas Russell and colleagues (2021) utilised Catapult ClearSky™ and an established operating technology (Second Spectrum, Los Angeles, United States) for the quantification of total distance covered by the basketball players.

Russell, McLean, Stolp, Strack, and Coutts (2021) quantified the external load of basketballers throughout an entire National Basketball Association season in training and competition using the Catapult ClearSky™ LPS and Optimal Tracking System (OTS). The types of activities completed by the basketball players to analyse the level of agreement between the LPS and OTS were skill, simulated gameplay, and match-play (Russell, McLean, Stolp, Strack, & Coutts, 2021). Russell, McLean, Stolp, Strack, and Coutts (2021) identified a strong level of agreement (93–99%) between the LPS and Second

Spectrum (OTS) for total distance covered. However, it is not mentioned how the LPS anchor nodes were positioned in comparison to the LPS MEMS devices as the positional conditions can negatively affect the positional accuracy of the LPS (Luteberget, Spencer, & Gilgien, 2018). There were significantly fewer differences between the LPS and a criterion reference system (Qualisys Oqus, Qualisys AB, Sweden) for quantifying total distance covered in the centre of the playing area (1-3%) compared to the side of the court (15-30%) (Luteberget, Spencer, & Gilgien, 2018). Luteberget, Spencer, and Gilgien's (2018) findings also showed that the mean difference between the LPS and criterion reference system (Qualisys) for total distance covered was <2% and <30% in optimal and sub-optimal conditions, respectively. Therefore, optimal conditions in a large indoor sports arena are the best conditions for the anchor nodes to keep the distances between the area of play, ceiling, corners, and walls constant (Luteberget, Spencer, & Gilgien, 2018).

Benson, Brooks, Bruce, and Fox (2020a) recorded the time-motion analysis variables supplied by the Catapult ClearSky™ LPS in elite netball match-play. Benson, Brooks, Bruce, and Fox (2020b) also quantified the physical movement demands of elite netball training and match-play across a full season of competition using the Catapult ClearSky™ LPS. Benson, Brooks, Bruce, and Fox (2020a; 2020b) monitored the physical demands (distance, velocity, acceleration, etc.) of each netball position at the elite level. Midcourt netball players (e.g., centre) had the highest total (4478.2 ± 1907.9m) distance covered by the Catapult ClearSky™ LPS in comparison to defenders (3150.3 ± 1765.3m) and goalers (3143.4 ± 1939.5m) in elite netball competitive match-play (Benson, Brooks, Bruce, and Fox, 2020a; 2020b). The Catapult ClearSky™ LPS relative distance covered data showed that the midcourter netball players also cover a greater distance per minute (56.67 ± 8.18m; 76.30 ± 9.74m) than the defenders (51.46 ± 7.91m; 59.67 ± 12.37m) and goalers (47.66 ± 9.16m; 58.22 ± 21.35m) within elite netball in-season training and competitive match-play. Midcourt netball players cover the greatest amount total and relative distance due to the court constraints imposed on the other netball positions (International Netball Federation, 2018). Whereas midcourt players are allowed to move into multiple areas of the netball court (International Netball Federation, 2018). Therefore, the Catapult ClearSky™

LPS can inform futsal practitioners of the physical demands of futsal if the LPS MEMS devices are worn throughout training and match-play (Ribeiro et al., 2020). The time-motion analysis variables monitored by the LPS would be beneficial to futsal as they can reveal the physical demands of each futsal position (Naser, Ali, & Macadam, 2017). Therefore, futsal practitioners could prescribe training load in order to prepare futsal players for the physical demands of match-play (Ribeiro et al., 2020). However, only one netball team's data, consisting of 10 players, was quantified in one venue as the LPS anchor nodes were fixed within one sporting venue throughout the competitive season (Benson, Brooks, Bruce, and Fox, 2020a; 2020b). LPSs lack of portability is detrimental to futsal practitioners as they do not allow a holistic view of the physical demands of futsal when training and or match-play is at alternative venue to the LPS (Torres-Ronda, Clubb, & Beanland, 2022).

Two studies attempted to validate the distance and (mean and instantaneous) velocity quantified by Catapult ClearSky™ against a criterion reference system (Serpiello et al., 2017; Luteberget, Spencer, & Gilgien, 2018). The criterion reference systems (Vicon™ or Qualisys™) for recording time-motion analysis variables utilises a reflective marker-based system (100Hz). Serpiello et al. (2017) attached two (14mm) reflective markers to each participant's receiver tag pouch whilst they performed the different activities to assess the validity of the ClearSky™ LPS. Whereas Luteberget, Spencer, and Gilgien (2018) attached one (12mm) reflective marker to their participant's receiver tag throughout the study. Serpiello et al. (2017) had their participants complete four linear movements ten times at various velocities including changes of direction (45˚) and a maximal acceleration. In contrast, Luteberget, Spencer, and Gilgien (2018) had the handball players perform five different movement tasks five times, such as a linear sprint with a deceleration, two diagonal movements (~75˚), and a zig zag (60˚). Instantaneous velocities had mean differences of > 35% recorded by the ClearSky™ LPS compared to Qualisys™ in optimal anchor node conditions (Luteberget, Spencer, & Gilgien, 2018). However, there was a mean difference between the ClearSky™ LPS and Vicon™ of 0.2-12% for peak velocities in optimal anchor node conditions (Serpiello et al., 2017). The differences in the findings of both these studies could have been a result of the additional changes of direction which the participants had to perform or the placement of the anchors in relation to the proximity of the data collection area (Luteberget, Spencer, & Gilgien, 2018). This is because the sensitivity of UWB is affected and dependent on the position of the anchor nodes in relation to area of play as well as turns and changes of direction (Bastida-Castillo et al., 2019b; Rico-González, Los Arcos, Clemente, Rojas-Valverde, & Pino-Ortega, 2020).

Another valid UWB LPS that have quantified time-motion analysis variables in professional futsal match-play is WIMU PRO™ (RealTrack System SL, Almería, Spain) (Illa, Fernandez, Reche, & Serpiello, 2021; Ribeiro et al., 2023). WIMU PRO™ was validated using a reference system of six and eight antennae respectively (Bastida-Castillo et al., 2019; Pino-Ortega, Bastida-Castillo, Gómez-Carmona, & Rico-González, 2020). It was emphasised that future LPS research should move towards using more than six antennae in a reference system as the eight antennae provided good accuracy for the time-motion analysis data (Pino-Ortega, Bastida-Castillo, Gómez-Carmona, & Rico-González, 2020). Even though there was a mean difference of 0.05m and 0.03m between the WIMU PRO™ LPS and the real measure for total distance covered, the procedure did not include any sharp changes of direction or turns that frequently occur within futsal match-play (Bastida-Castillo et al., 2019b; Pino-Ortega, Bastida-Castillo, Gómez-Carmona, & Rico-González, 2020). This is important because UWB LPSs are sensitive to changes of direction depending on antennae position in reference to the area of play (Bastida-Castillo et al., 2019b; Rico-González, Los Arcos, Clemente, Rojas-Valverde, & Pino-Ortega, 2020). The reference system used to validate WIMU PRO™ was set up using the same optimal conditions as a study that attempted to validate Catapult ClearSky™ (Luteberget, Spencer, & Gilgien, 2018; Bastida-Castillo et al., 2019b). Therefore, Catapult ClearSky™ is a viable LPS to compare the time-motion analysis variables of PlayerMaker™ against within an indoor environment.

Vicon™ (Oxford Metrics, Ltd, Oxford, United Kingdom) is a criterion (gold-standard) reference system for quantifying time-motion analysis data within an indoor environment (Hodder, Ball, & Serpiello, 2020). The Vicon™ system requires multiple infrared cameras to be set up around and near the physical activity area and infrared reflective markers with a capture frequency of 100Hz (Hodder, Ball, & Serpiello, 2020). Previous research has compared the time-motion analysis variables of Vicon™ to an LPS with reflective markers worn on the body of the research participants (Hodder, Ball, & Serpiello, 2020; Fuchs, Chou, Chen, Fiolo, & Shiang, 2023). Hodder, Ball, and Serpiello (2020) used the Vicon™ system to validate the inter-unit distance of an LPS at distances of various lengths (0-5m; 5-10m; 10-15m; 15-20m; > 20m). Hodder, Ball, and Serpiello (2020) observed acceptable inter-unit distance between an LPS and Vicon™ as there was a mean root mean square error of 0.2 ± 0.05m. In contrast, Fuchs, Chou, Chen, Fiolo, and Shiang, (2023) measured the accuracy of maximum velocities, accelerations, and decelerations quantified by an LPS against Vicon by performing four different tasks at low and maximum efforts (curved and linear side-ways shuttle runs, triangular and straight line runs). The maximum velocities measured by Vicon™ and an LPS showed a strong to excellent concordance correlation coefficients level of agreement (95%CI: 0.883– 0.950) (Fuchs, Chou, Chen, Fiolo, & Shiang, 2023). Despite Vicon™ being the criterion reference system, an LPS has shown acceptable levels of validity for time-motion analysis variables against Vicon™ (Hodder, Ball, & Serpiello, 2020; Fuchs, Chou, Chen, Fiolo, & Shiang, 2023). As the Vicon™ reflective markers could have fallen off during futsal match-play, the collection of time-motion analysis data would have been disrupted. The limited space around the futsal court means that the presence of multiple infrared cameras surrounding the court would have been hazardous for the participants.

Qualisys Oqus™ (Qualisys AB, Sweden) is another motion capture system, that is also a criterion system for the quantification of time-motion analysis data (Adesida, Papi, McGregor, 2019). The use of an infrared camera system allows Qualisys™ to have a data capture frequency rate of 120Hz and a high level of accuracy (Blauberger, Marzilger, & Lames, 2021). It has been emphasised that Qualisys™ (or a criterion reference system) is paramount for validating a positional tracking system (Luteberget & Gilgien, 2020). Qualisys™ been previously used within research to validate two different LPSs including Catapult ClearSky™ (Luteberget, Spencer, & Gilgien, 2018; Blauberger, Marzilger, & Lames, 2021). Blauberger, Marzilger, and Lames (2021) had the Qualisys™ cameras set up around the balcony of the testing area to calculate a precise 3D location of the reflective markers. Total distance covered, maximum velocities, peak accelerations, and decelerations of professional handball players in sports-specific courses and small-sided games of indoor football using an LPS (Kinexon) and Qualisys™ (Blauberger, Marzilger, & Lames, 2021). Whereas Luteberget, Spencer, and Gilgien (2018) placed the infrared cameras on tripods around the data collection area to monitor total distances covered (in various velocity thresholds), as well as mean and instantaneous velocities in various physical activity tasks. Even though the Qualisys™ cameras could be set up above and around a physical activity area and for small-sided games of indoor football, the Qualisys™ system would have been too expensive to obtain (Do Carmo Vilas-Boas, Choupina, Rocha, Fernandes, & Cunha, 2019).

Catapult ClearSky™ was the LPS chosen to compare the time-motion analysis variables of PlayerMaker™ to, despite there being alternative LPSs and motion capture systems for quantifying the time-motion analysis data of indoor sports. The acceptable validity for distance covered and velocity makes Catapult ClearSky™ a viable alternative to the criterion systems (Luteberget, Spencer, & Gilgien's, 2018). The alternative LPSs were similar to Catapult ClearSky™ due to their use of UWB to quantify time-motion analysis data. Although the Vicon™ and Qualisys™ motion capture systems are the criterion systems for quantifying time-motion analysis data indoors, the previous research that validated the Catapult ClearSky™ LPS had the participants complete exercises that were short in distance and duration (Luteberget, Spencer, & Gilgien's, 2018). Therefore, Vicon™ and Qualisys™ would not have been appropriate for the present research due to their systems use of reflective markers potentially falling off the participants throughout futsal match-play. Even though the motion capture systems could have validated the LPS and FIMUs , the expensive financial cost of the motion capture systems prevented this (Do Carmo Vilas-Boas, Choupina, Rocha, Fernandes, & Cunha, 2019). Therefore, setting the antennae up around the ceiling, above the futsal court and housing the LPS measuring devices within the manufactured supplied vests were the most appropriate actions . Although there have been previous studies where PlayerMaker™ has been compared with motion capture camera systems and GPS (Myhill, Weaving, Robinson, Barrett, & Emmonds, 2023), there is no research to our knowledge comparing the PlayerMaker™ foot-mounted inertial measurement units (FIMU) against an LPS.

2.3 Foot-Mounted Inertial Measurement Units

FIMUs can quantify technical footballing actions through gait phase detection and a machine learning algorithm (Waldron, Harding, Barrett, & Gray, 2020). The FIMUs are comprised of a triaxial accelerometer and gyroscope in each sensor to quantify the time-motion analysis data (Waldron, Harding, Barrett, & Gray, 2020). The commercially available FIMUs (PlayerMaker™, Tel-Aviv, Israel) have been recently granted permission from the International Football Association Board to be worn in official football matches (PlayerMaker, 2023). Previous literature is limited to training and academy football (Marris, Barrett, Abt, & Towlson, 2022; Emmonds et al., 2023; Salter et al., 2023). However, previous research has assessed the time-motion analysis data of FIMUs against commercially available GPS devices (Waldron, Harding, Barrett, & Gray, 2020; Lewis et al., 2022; Sandmael & Dalen, 2023). The time-motion and gait analysis data recorded by the PlayerMaker™ FIMUs includes distance covered (across velocity thresholds), (maximum) velocity, acceleration(s), deceleration(s), and changes of direction (turns) (Waldron, Harding, Barrett, & Gray, 2020).

Inter and Intra-Device Reliability of FIMUs

The inter-device reliability of the PlayerMaker™ FIMUs is essential to the collection of consistent time-motion analysis data across the system (Waldron, Harding, Barrett, & Gray, 2020). The inter-device reliability of the FIMUs has been previously assessed with seven participants wearing two of the FIMUs on each foot and having the participants complete the SAFT90 protocol (Waldron, Harding, Barrett, & Gray, 2020). The PlayerMaker™ FIMUs inter-device reliability assessment of the total distance covered (-0.16 ± 1.28 m) and maximum velocity (0.06 ± 0.25 m/s) showed no significant inter-device variation (Waldron, Harding, Barrett, & Gray, 2020). Therefore, sporting practitioners can trust the repeatability of the time-motion analysis data measured by the FIMU system (Crang et al., 2021).

The intra-device reliability is necessary for monitoring the time-motion analysis within the same FIMUs to show that have strong test-retest capabilities (Sandmael & Dalen, 2023). The intra-device reliability of the FIMUs has been tested during a square running protocol (SRP), where the four participants wore two FIMUs on each foot (Sandmael & Dalen, 2023). The SRP was total distance of 1205m, where the participants ran five laps of 241m altogether. The intra-device reliability of the FIMUs from the SRP was acceptable as the co-efficient of variation was ~1% (Sandmael & Dalen, 2023). As there is limited research carried out on the intra-device reliability of the FIMUs in football (Sandmael & Dalen, 2023), it recommended that same FIMU is worn consistently by the same athlete if possible (Waldron, Harding, Barrett, & Gray, 2020). This should allow the MEMS device to detect any changes in an athlete's physical performance in their sport over time (Düking, Fuss, Holmberg, & Sperlich, 2018).

The Application and Attempted Validation of FIMUs

The PlayerMaker™ FIMUs have the capacity to quantify time-motion analysis data indoors and outdoors (Sandmæl, Van den Tillaar, & Dalen, 2023). The previous PlayerMaker™ studies that have quantified time-motion analysis data within indoor environments are limited (Myhill, Weaving, Robinson, Barrett, & Emmonds, 2023; Sandmæl, Van den Tillaar, & Dalen, 2023). The previous studies analysed the concurrent validity of the PlayerMaker™ FIMUs indoors against Polar Team Pro devices and multi-camera motion analysis system (Qualisys™) (Myhill, Weaving, Robinson, Barrett, & Emmonds, 2023; Sandmæl, van den Tillaar, & Dalen, 2023). Myhill, Weaving, Robinson, Barrett, and Emmonds (2023) chose to compare the PlayerMaker™ FIMUs against Qualisys™ as the motion capture system is the gold standard for quantifying time-motion analysis data. Myhill, Weaving, Robinson, Barrett, and Emmonds (2023) measured the distance, velocity, acceleration, and deceleration parameters because of their constant use for quantifying the physical demands of professional team sport (Coutts & Duffield, 2010). Whereas Sandmæl, Van den Tillaar, and Dalen (2023) chose to compare the PlayerMaker™ FIMUs to a chest worn wearable device because previous research had already compared the PlayerMaker™ FIMUs to multiple GPS devices (Waldron, Harding, Barrett, & Gray, 2020). Furthermore, Polar Team Pro devices were used as the researchers wanted to compare the data monitored by the PlayerMaker™ FIMUs and Polar Team Pro devices quantified indoors and outdoors (Sandmæl, Van den Tillaar, & Dalen, 2023). However, these studies did not compare PlayerMaker™ to an UWB based local positioning system (Myhill, Weaving, Robinson, Barrett, & Emmonds, 2023; Sandmæl, Van den Tillaar, & Dalen, 2023).

The procedures (physical activities) for data collection to validate the occurred within a closed environment rather than match-play (Myhill, Weaving, Robinson, Barrett, & Emmonds, 2023; Sandmæl, Van den Tillaar, & Dalen, 2023). The Myhill, Weaving, Robinson, Barrett, and Emmonds (2023) procedures consisted of a maximal acceleration drill, flying a 10 metre sprint, and a SAFT90 (team sport simulation shuttle course). The activities were chosen by Myhill, Weaving, Robinson, Barrett, and Emmonds (2023) as they can replicate the physical and physiological demands of team sport (Lovell, Knapper, & Small, 2008). Whereas the Sandmæl, Van den Tillaar, and Dalen (2023) procedures included straight line runs and changes of direction in a 30m x 20m rectangle that were ran indoors and outdoors. Sandmæl, Van den Tillaar, and Dalen (2023) chose the procedures for their study as it enabled the researchers to test the validity and reliability of the two systems across multiple velocity thresholds. Both studies had the participants wear two pairs of PlayerMaker™ FIMUs, enabling a between-unit reliability analysis of the PlayerMaker™ FIMUs within the time-motion analysis data (Myhill, Weaving, Robinson, Barrett, & Emmonds, 2023; Sandmæl, van den Tillaar, & Dalen, 2023). Van den Tillaar, Gaustad Pettersen, and Lagestad (2023) found that the distance covered, and velocity data metrics recorded by the Polar Team Pro devices were underestimated when compared against the criterion systems. The variation in these results were due to the anatomical placement of the chest strap and the body height of the wearer as they could have affected the data collection algorithm of the Polar Team Pro (Van den Tillaar, Gaustad Pettersen, & Lagestad, 2023). In contrast, Myhill, Weaving, Robinson, Barrett, and Emmonds (2023) had the Qualisys™

motion capture markers and PlayerMaker™ FIMUs located on the shoes of the research participants. Therefore, the researchers were able to analyse the steps and changes of direction more accurately as the FIMUs were worn on the participant's footwear (Waldron, Harding, Barrett, & Gray, 2020).

The PlayerMaker™ FIMUs are the only commercially available foot-mounted IMUs with the capabilities to quantify time-motion analysis variables and technical soccer variables (Marris, Barrett, Abt, & Towlson, 2022). Although football has not been part of the previous research, FIMUs have quantified time-motion analysis data (Enomoto, Suzuki, Hahn, Aibara, & Yahata, 2020; Zhang et al., 2020; Suzuki, Hahn, & Enomoto, 2022; Young et al., 2022). However, the FIMUs in the Enomoto, Suzuki, Hahn, Aibara, and Yahata (2020) study were clipped onto the dorsum of the foot to estimate ground reaction forces during running. Despite Suzuki, Hahn, and Enomoto (2022) having their participants wear two pairs of FIMUs for intra-unit reliability, the FIMUs were also fixated on the dorsum of the foot (shoes) to estimate foot trajectory and stride length. This would have increased the likelihood of the FIMUs being damaged or falling off during futsal match-play. Furthermore, the PlayerMaker™ FIMUs have a higher sampling rate (1000Hz) than the FIMUs in both studies (200Hz) (Enomoto, Suzuki, Hahn, Aibara, & Yahata, 2020; Suzuki, Hahn, & Enomoto, 2022) and can quantify the technical variables within football (Marris, Barrett, Abt, & Towlson, 2022). Although the FIMUs were able to quantify angular velocity and acceleration data, another drawback included the drift in the velocity and acceleration data, causing errors to occur within the dataset (Enomoto, Suzuki, Hahn, Aibara, & Yahata, 2020; Suzuki, Hahn, & Enomoto, 2022).

The FIMUs within previous research, that are not commercially available, were able to analyse the motion and gait of the wearers (Zhang et al., 2020; Young, et al., 2022). Despite the previous studies not involving football, the FIMUs were fixated on the top of the participant's footwear (Zhang et al., 2020; Young, et al., 2022). Neither of the previous studies involved any physical contact with any other participants or a ball, which could have damaged the FIMUs should it have occurred (Zhang et al., 2020; Young, et al., 2022). The FIMUs in the Young et al. (2020) study were worn whilst the participants ran on a treadmill. Whereas Zhang et al. (2020) had their participants walk around a rectangular path to monitor the positions of the participants. Although the FIMUs were taped to the footwear of the participants to prevent them falling off (Young, et al., 2022), the FIMUs would have been unable to quantify the technical variables of football as PlayerMaker™ put their FIMUs through a machine learning algorithm (Waldron, Harding, Barrett, & Gray, 2020). Despite the Axivity FIMUs in the Zhang et al. (2020) study having a sampling frequency of 60Hz and showing strong levels of agreement with the criterion motion capture system, neither study involved changes of direction or sudden changes in speed that would occur in futsal (Zhang et al., 2020; Young, et al., 2022).

Overall, the PlayerMaker™ FIMUs were the best option for the present study due to their ability to quantify time-motion analysis and technical football performance data indoors and outdoors. Although the PlayerMaker™ FIMUs have not been compared against an UWB LPS, Sandmæl, Van den Tillaar, & Dalen's (2023) findings showed that the PlayerMaker™ FIMUs had good accuracy for measuring time-motion analysis variables indoors. In addition, the PlayerMaker™ FIMUs are enclosed on the outside of the participant's footwear, so were not exposed to the ball (Waldron, Harding, Barrett, & Gray, 2020). Whereas the FIMUs within previous research were all fixated on the top of the wearer's feet, leaving the FIMUs exposed to contact with the futsal ball if they were worn throughout match-play (Enomoto, Suzuki, Hahn, Aibara, & Yahata, 2020; Zhang et al., 2020; Suzuki, Hahn, & Enomoto, 2022; Young et al., 2022). Marris, Barrett, Abt, and Towlson (2022) established the concurrent validity of the PlayerMaker™ FIMUs for quantifying the technical variables of football. Marris, Barrett, Abt, and Towlson (2022) observed a high proportion of agreement for ball touches (95.1%) and ball releases (97.6%). In contrast, the FIMUs within previous studies were unable to quantify the technical variables of football (Enomoto, Suzuki, Hahn, Aibara, & Yahata, 2020; Zhang et al., 2020; Suzuki, Hahn, & Enomoto, 2022; Young et al., 2022).

2.4 Technical Sports Performance Data

Sports performance analysts quantify the technical actions performed by athletes, which are specific to the sport being played (Hughes & Bartlett, 2002). In futsal, the athletes are required to perform technical actions such as passing, shooting, and dribbling (Mohammed, Shafizadeh, & Platt, 2014). Futsal players that compete in a higher standard of competition will have greater technical abilities compared to the amateur players. The technical performance data in futsal match-play ranges from ball possession percentages to pass completion (Ismail & Nunome, 2020). Futsal coaches utilise the technical performance data to inform their team selection and match strategy pre-match and mid-match (Almeida, Sarmento, Kelly, & Travassos, 2019). As a result of the limited time in between competition during a season, the days in between matches are utilised for recovery and training sessions (Dellal, Lago-Peñas, Rey, Chamari, & Orhant, 2015). Therefore, sports coaches require the technical performance data to be provided to them during their matches or shortly afterwards for post-match analysis (Sarmento et al., 2018).

A high pass completion rate is an important technical performance indicator for futsal (Yiannaki, Barron, Collins, & Carling, 2020). Futsal players are required to pass the ball successfully between each other to create goal scoring opportunities and maintain possession of the ball for their team (Ismail & Nunome, 2020). This subsequently reduces the goal scoring opportunities for the opposing team (Ismail & Nunome, 2020). Although a futsal team's number of passes and pass completion rate can be high, previous research found no correlation in the number of passes attempted and completed for a professional futsal team to be successful across 40 matches (Santos, Mendez-Domínguez, Nunes, Gómez, & Travassos, 2020). Yiannaki, Barron, Collins, and Carling (2020) state that an elite futsal team averages around 647 attempted passes per 40-minute match. Previous research has shown that there is ~90% and ~76% pass completion in professional and elite futsal respectively (Owen, Wong, Paul, & Dellal, 2014; Mohammed, Shafizadeh, & Platt, 2014). Even though there was no correlation between pass completion rate and victory in professional futsal, unsuccessful passes near a futsal team's goal net will lead to a greater number of goals conceded as there is an increased possibility of scoring the closer a player is to the goal net (Vilar, Araújo, Davids, Travassos, Duarte, & Parreira, 2014).

The number of ball touches is another technical performance variable of futsal that is imperative to participation (Dogramaci, Watsford, & Murphy, 2015; Mănescu, 2016; Reis et al., 2019). Even though the previous research on the number of touches in futsal matches is limited, sub-elite futsal teams of competitive quality averaged 3-4 ball touches per minute throughout futsal match-play (Dogramaci, Watsford, & Murphy, 2015). Whereas an outfielder will have ~80 touches throughout an average 40-minute futsal match (Mănescu, 2016). Dogramaci, Watsford, and Murphy (2015) analysed four matches from two teams and five matches from one team in their study across three different leagues and countries. Although a larger sample size would have allowed for a more thorough analysis to be completed, Dogramaci, Watsford, and Murphy's (2015) analysis of sub-elite futsal teams found that the more successful futsal teams averaged fewer touches per minute (3) than the unsuccessful teams (4). This emphasises a necessity to pass the ball with fewer touches to maintain possession and create chances to score goals (Mănescu, 2016). However, futsal players could increase their number of ball touches if the opposition decide against pressuring the players on the ball or have a player or players dismissed from the match (Gómez, Méndez, Indaburu, & Travassos, 2019). Although previous research has quantified the number of touches in futsal, the number of successful and unsuccessful touches in futsal has not been measured. This is important as futsal players need successful ball touches to keep the ball close to their feet and in the dimensions of the court to prevent losing possession of the ball (Mănescu, 2016).

Dribbling is another important technical futsal skill, which involves the players moving the ball on and around the court with the various parts of their feet (Amaral & Garganta, 2005). Elite futsal players averaged 0.9 successful dribbles per 40-minute match and 0.05 successful dribbles per minute (Spyrou et al., 2023). Furthermore, elite futsal players averaged a successful dribble rate of 39.06%

(Santos, Mendez-Domínguez, Nunes, Gómez, & Travassos, 2020). Although progressing and maintaining possession of the ball is a key reason for dribbling in futsal (Amaral & Garganta, 2005), there were no differences in the number of dribbles and dribbling success rate on futsal match outcomes (Santos, Mendez-Domínguez, Nunes, Gómez, & Travassos, 2020). However, elite futsal teams that won more matches achieved a greater number of dribbles (25.2 ± 9.81) and successful dribble rate (46.14%) compared to the futsal teams that lost more matches (22.48 ± 8.1; 42.97%) (Santos, Mendez-Domínguez, Nunes, Gómez, & Travassos, 2020). In addition, previous research has placed a high level of importance of when to dribble in a futsal match as players could lose possession of the ball if they dribble at the wrong moments (Corrêa, de Pinho, da Silva, Clavijo, Souza, & Tani, 2016). Futsal players are influenced to dribble based on shooting angle, passing angle, and interpersonal distance between themselves and opposing team players whilst they have possession of the ball (Corrêa et al., 2016). Even though dribbling can create passing angles in futsal (Corrêa et al., 2016), there is a greater emphasis on passing in elite futsal with the appropriate timing and intensity due to opposing team's players ability to intercept and regain possession of the ball (Davids, Araujo, & Shuttleworth, 2005).

A technical futsal performance parameter that is quantified within futsal match-play is ball possession (Abdel-Hakim, 2014; Dogramaci, Watsford, & Murphy, 2015; Gómez, Méndez, Indaburu, & Travassos, 2019; Ismail & Nunome, 2020; Santos, Mendez-Domínguez, Nunes, Gómez, & Travassos, 2020). This is because ball possession is calculated through the total time spent with the ball (Collet, 2013). In the 40 matches throughout the 2016 Futsal World Cup, the winning teams averaged 52% ball possession, and the losing teams averaged 48% ball possession (Ismail & Nunome, 2020). The results of the Ismail and Nunome (2020) study showed that a team's ball possession percentage did not contribute to the match results across the whole of the tournament. These results concurred with the results of the previous literature (Abdel-Hakim, 2014; Santos, Mendez-Domínguez, Nunes, Gómez, & Travassos, 2020), where ball possession percentages did not contribute to teams winning, drawing, and losing in elite futsal matches. In contrast to the Ismail and Nunome (2020) research, Dogramaci, Watsford, and Murphy's (2015) findings showed that more successful futsal teams had a greater ball possession percentage in matches than unsuccessful teams. Furthermore, the teams that reached the semi-finals of the 2016 Futsal World Cup averaged greater ball possession (53%) than the teams that lost most of their matches in the tournament (47%). Although ball possession did not affect the match result across the 2016 Futsal World Cup, teams with greater ball possession in their own defense and attack led to winning more futsal matches. This is the case because the longer a futsal team has ball possession near the opposition goal net, the more opportunities a team will have to score goals (Corrêa, Oliveira, Clavijo, Letícia da Silva, & Zalla, 2020).

Another technical futsal performance skill that is quantified within every level of futsal is shooting (on/ off target) (Santos, Mendez-Domínguez, Nunes, Gómez, & Travassos, 2020; Spyrou et al., 2023). Elite outfield futsal players with a high active time on the court averaged 4.2 total shots and 1.7 shots on target per 40-minute match (Spyrou et al., 2023). However, futsal players with less time on the court had more total shots (0.3) and shots on target (0.1) per minute than those who spent more time on court (Spyrou et al., 2023). Spyrou et al. (2023) observed more goals scored by futsal players who attempted more shots on target. Therefore, shooting is a key technical performance action that needs to be developed by futsal players for them to be successful. However, Spyrou et al. (2023) researched the total futsal shots and goals across 15 matches in three futsal competitions, the research does not mention how the total number of shots and shots on target affected the futsal match outcome. However, previous research showed that the total shots and shots on target in a futsal match did not affect futsal match outcomes (Miloski, Pinho, Freitas, Marcelino, & Arruda, 2014; Santos, Mendez-Domínguez, Nunes, Gómez, & Travassos, 2020). This could be due to the total number of shots and shots on target failing to indicate the probability of shots being scored (Mulazimoglu, Tokul, Can, & Eyuboglu, 2024). Whereas previous studies have shown that futsal teams won more matches if they had more shots and shots on target (Souza, Ribeiro, Rocha, Fernandes, & Moreira, 2013; Abdel-Hakim, 2014; Göral, 2018). Despite the failing to indicate the likelihood of a shot leading to a goal, winning teams in a futsal World Cup averaged ~9 more total shots (39.12 ± 12.69) and ~7 more shots on target (17 ± 6.28) than the losing teams (30.41 ± 10.87; 10.39 ± 4.85) across 48 matches (Abdel-Hakim, 2014).

2.5 The Technical Performance Data of PlayerMaker™

There is yet to be any research to our knowledge that has been carried out that has utilised the PlayerMaker™ FIMUs for quantifying the technical actions within futsal. The PlayerMaker™ FIMUs can record numerous technical footballing actions of the wearers, where the ball encounters the IMU (Myhill, Weaving, Robinson, Barrett, & Emmonds, 2023). Therefore, the technical sports performance analysis process can be sped up using the PlayerMaker™ FIMUs, rather than the traditional time-consuming video analysis (Lewis et al., 2022). Even though video analysis is the traditional method of measuring technical sporting variables, there is no gold standard due to video analysis being subjective and dependent on the sporting knowledge of the video analyst (Hood, McBain, Portas, & Spears, 2012). This led to video analysis software being used as a surrogate method within the present study. Although the time-motion analysis or technical performance data derived from the PlayerMaker™ FIMUs cannot be viewed live, a comparison between the technical performance data of the PlayerMaker™ FIMUs against traditional notational analysis will be beneficial in the present study because of the limited available research concurrently validating the technical performance data quantified by the FIMUs in match-play (Marris, Barrett, Abt, & Towlson, 2022).

Ball touches can be measured by the PlayerMaker™ FIMUs and this is the number of times the ball interacts with either foot of the wearer (Emmonds et al., 2022). The ball touches data could be useful to football coaches to provide them with insights into the demands of each position and the technical capabilities of each player as the best footballers are able to play with fewer touches per ball possession to increase the speed of the play (Dellal, Lago-Penas, Wong, & Chamari, 2011). As the PlayerMaker™ FIMUs were designed for football, the previous research using the FIMUs has been in football (Towlson et al., 2021; Marris, Barrett, Abt, & Towlson, 2022; Lewis et al., 2022; Emmonds et al., 2022). Marris, Barrett, Abt, and Towlson (2022) explored the concurrent validity of the FIMUs for quantifying technical footballing actions. They observed a 95.1% level of agreement between the FIMUs and video analysis from 8640 ball touches during technical football tasks (Marris, Barrett, Abt,

& Towlson, 2022). As the coefficient of variation percentage (CV%) level of agreement for ball touches was < 5.0%, a ball touch was viewed as a concurrently valid technical performance variable to be analysed in the present study (Scott, Scott, & Kelly, 2016).

Another technical performance variable recorded by the PlayerMaker™ FIMUs is a ball release(s). A ball release is an action where a player kicks the ball with either foot (Losada Benitez, Nuñez, & Barbero-Álvarez, 2023), which could be either a shot, cross, pass, or clearance. However, the PlayerMaker™ FIMUs are unable to differentiate between the different actions that could occur from ball releases (Marris, Barrett, Abt, & Towlson, 2022). Ball releases within the Marris, Barrett, Abt, and Towlson (2022) research had a 97.6% level of agreement from 5760 ball releases between video analysis and the PlayerMaker™ FIMUs. Although the FIMUs ability to quantify technical performance variables in match-play has not been thoroughly analysed, the CV% of ball releases within the Marris, Barrett, Abt, and Towlson's (2022) research was < 5.0%, making ball releases a concurrently valid technical performance variable to be analysed within the present study (Scott, Scott, & Kelly, 2016).

The PlayerMaker™ FIMUs are also able to separate ball releases and ball touches that they quantify into dominant and non-dominant leg (Lewis et al., 2022). The ability of the PlayerMaker™ FIMUs to quantify leg use is important for the wearers because footballers (and futsal players) require the ability to use both feet to increase their technical performance skills (Grouios, Kollias, Koidou, & Poderi, 2002). Lewis et al. (2022) suggests that professional footballers decrease the use of their non-dominant foot to release the ball the closer they get to a matchday. However, this would be a result of the physical demands of training gradually decreasing as match-day approaches (Martín-García, Díaz, Bradley, Morera, & Casamichana, 2018). However, the research on the dominant and non-dominant feet ball releases and ball touches is limited, the dominant and non-dominant feet data recorded by the FIMUs were not included in the present study's results.

The technical match-play variables of football can also be measured by the PlayerMaker™ FIMUs. These variables consist of ball possessions, pass completion rate, and passing networks

(Towlson et al., 2021; Losada Benitez, Nuñez, & Barbero-Álvarez, 2023). A technical load analysis of the individual players and teams can be conducted as the FIMUs can measure and differentiate between them (Losada Benitez, Nuñez, & Barbero-Álvarez, 2023). These previous studies emphasised the importance of analysing technical load due to the differing technical demands of footballing playing position (Towlson et al., 2021; Losada Benitez, Nuñez, & Barbero-Álvarez, 2023). Despite the FIMUs ability to record these technical performance variables, these statistics are influenced by quality of the opposition team, match outcome, and the strategies of both teams, etc. (Lago, 2009). Even though previous research has quantified these technical match-play variables within small sided games and match-play (Towlson et al., 2021; Losada Benitez, Nuñez, & Barbero-Álvarez, 2023), the passing dataset was not included within the results of the present study due to the FIMUs inability differentiate between a pass and a shot (Marris, Barrett, Abt, & Towlson, 2022).

The data measured by the FIMUs on ball possessions and passing can be further broken down into variables such as short and long possessions, percentage of ball possession, and passes per possession (Lewis et al., 2022). Despite these variables providing an insight into bio-banding within footballing academies and the technical demands of pre-season professional football friendlies, this data would not be meaningful for the present study (Towlson et al., 2021; Losada Benitez, Nuñez, & Barbero-Álvarez, 2023). This is because previous research showed that ball possession was not a contributing factor to successful match-outcome in futsal (Ismail & Nunome, 2020). Therefore, the technical performance variables measured by the FIMUs in the present study were limited to the number of ball touches and ball releases completed.

This literature review shows that a local positioning system is the main method for quantifying time-motion analysis data indoors and within previous futsal research (Serpiello et al., 2017; Serrano et al., 2020; Illa, Fernandez, Reche, & Serpiello, 2021). Although motion capture systems are the criterion system for quantifying time-motion analysis data (Serpiello et al., 2017; Luteberget, Spencer, & Gilgien, 2018), the FIMUs can quantify time-motion analysis data indoors (Myhill, Weaving, Robinson, Barrett, & Emmonds, 2023). The previous research has shown that the most important time-motion analysis variables in futsal are relative due to the unlimited substitution rule and match clock stopping every time the ball is not in play (Barbero-Alvarez, Soto, Barbero-Alvarez, Granda-Vera, 2008). The technical load of footballers can be measured through the FIMUs (Losada-Benitez, Nuñez-Sánchez, & Barbero-Álvarez, 2023), however the concurrent validity of the FIMUs for quantifying the technical variables has yet to be thoroughly researched within match-play (Marris, Barrett, Abt, & Towlson, 2022). Despite a plethora of technical futsal actions that are key to participation in futsal, including dribbling, passing, and shooting, the FIMUs are unable to differentiate between passes and shots (Towlson et al., 2021). This research will aim to concurrently validate the FIMUs time-motion analysis data against a local positioning system as this has yet to be researched. A high level of agreement between the FIMUs and a local positioning system is important as the FIMUs could be a cheaper alternative for quantifying time-motion analysis indoors. This study also intends to concurrently validate the technical futsal variables of the FIMUs within match-play as these variables have not been quantified within futsal. The utilisation of the FIMUs for quantifying the technical variables of futsal is key as it shows whether the FIMUs could be used to monitor the technical load of futsal players within match-play.

3.0 Chapter 3: Methods

3.1 Participants

Having ethical approval (see approval letter in the Appendix B) and using convenience sampling techniques (Etikan, Musa, & Alkassim, 2015), the present study recruited 28 male participants (mean ± SD age: 32.8 ± 11.7 years; stature: 179.6 ± 8.8 cm; mass: 83.4 ± 12.2 kg) that played recreational futsal at the University of Hull to take part in a descriptive, cross-sectional study design. A convenience approach to sampling enabled the principal investigator to recruit participants that were near the data collection location and individuals that were readily available to participate in the study on a data collection day (Dörnyei, 2007). Despite the initial approaches made to a futsal team to participate in the present study, the hinderances of the wearable technology throughout their futsal performances prevented their participation. Even though a convenience approach to sampling was undertaken, the present study's sample size was still constrained by the number of participants (of any gender), aged 18 and over, that were fit and able to play futsal on each data collection day. A convenience approach to sampling was taken in the present study as it is common within developmental science due to the increased availability of participants and low financial cost (Jager, Putnick, & Bornstein, 2017).

The match-to-match variation data analysis required participants to consistently attend the data collection sessions for meaningful results to be shown. The lead researcher of the present study utilised an existing relationship with the sport development officers at the University of Hull Sport Centre to act as gatekeepers for the University's staff. The research participants within the present study were made aware of the study via written communication in the University of Hull staff futsal group. If there were any participants not a part of the University of Hull staff, they were recruited and informed about the aims of the study via the principal researcher's verbal explanation and participation sheet (Appendix B) before a data collection session. Informed consent forms were signed electronically prior to the data collection period or signed physically prior to a participant's first data collection session.

3.2 Research Design

The present study had a cross-section, descriptive research design. Two teams of five participants for the futsal matches were separated into “Team A" and “Team B” on each data collection day. The research participants played in an average of 11 ± 10 out of the 26 futsal games with usable data for the present study. The data from the pilot session and session 12 had to be removed from the data analysis due to a technological issue. This technological issue occurred because of the device type (LPS ClearSky) not being correctly selected from the list of options on the OpenField software prior to the beginning of session 12. A pilot session was undertaken in the present study to provide the participants with the opportunity to familiarise themselves with the wearable technology which they would be using for the study. The pilot session was necessary as the time and access to the participants and venue was limited. The data from the pilot session has been removed from the study as the futsal games were not ten-minutes in duration.

There was a total of 13 usable data collection sessions, consisting of 26 games of futsal that were eligible to be included in the research analysis for the present study. The data collection of the present study’s participants included the time-motion analysis data quantified by the foot-mounted inertial measurement units (PlayerMaker™, Israel) and the local positioning system MEMS devices (Catapult ClearSky™, Australia). Furthermore, the data collection sessions were video recorded (Sony HDR CX240) to compare the technical futsal performance data quantified by the foot-mounted inertial movement units (PlayerMaker™, Israel) and video analysis (Catapult Vision™) data analysed by the principal investigator.

The present study consisted of wearable sports performance data (See Appendix C), including time-motion analysis variables (total distance, maximum velocity, sprints, and distance covered within velocity thresholds) and technical futsal performance variables (ball touches and ball releases). This wearable performance data was collected from total of 15 research sessions, from January 2023 to June 2023 [days between sessions, 11 ± 8 days; Mean ± Standard Deviation (SD)]. Each research session included two 10-minute games of futsal. The open futsal match-play data collection sessions occurred at midday on Tuesdays when the University of Hull's sport centre futsal court was available. The principal investigator was responsible for setting up the wearable devices and monitoring the time-motion analysis data from the futsal match-play. The FIMUs and MEMS devices were fully charged and activated 30 minutes prior to each data collection session. The research participants were required to wear the PlayerMaker™ and Catapult ClearSky™ devices concurrently, housed in their respective manufacturer supplied vests and silicone straps. Warm-ups and cool downs were not included for the open match-play futsal sessions due to the limited amount of time the participants had.

3.3 Inertial Measurement Units

Both the technical and physical futsal performance data were quantified through the foot-mounted inertial measurement units (IMU) (PlayerMaker™, Tel Aviv, Israel). The PlayerMaker™ sensors incorporate two components from the MPU-9150 multi-chip motion tracking module (InvenSense, California, USA), including a 16g triaxial accelerometer and a 2000°•s−1 triaxial gyroscope. Housed in manufacturer-supplied tightly fitting silicone straps, each participant was equipped with two sensors (one for each foot), which were located at the lateral malleoli over the participants trainers.

The FIMUs quantify the frequency (*f*) of foot-based performance data by tracking ball to foot interactions (Marris, Barrett, Abt & Towlson, 2022) including ball releases (total, dominant leg, non-dominant), ball touches (total, dominant leg, non-dominant), and ball possessions (See Appendix D) (Lewis et al., 2022). Each player had a profile created on PlayerMaker™ online dashboard, which included information to denote the participant's dominant foot, height (cm), mass (kg), playing position, nationality, and each foot's sensor. Each pair of sensors were switched on through Bluetooth connection with an iPad (Apple Inc, California), on the PlayerMaker™ application (version 3.27), before each data collection session. The data was uploaded to the PlayerMaker™ online cloud after each data collection session. The beginning and ending of the data collection sessions were timed in conjunction with the live LPS software and then inserted onto the PlayerMaker™ online dashboard.

3.4 Local Positioning System

The local positioning system (Catapult ClearSky, Catapult Sports, Melbourne, Australia) and the activated lightweight (53g) S7 devices (8.1 × 4.3 × 1.6 cm) (Catapult ClearSky S7, Catapult Sports, Melbourne, Australia: firmware version 8.1.0) were utilised through the appropriate software (Catapult OpenField™, version 3.9.1 Build, Catapult Sports). The S7 MEMS (micro-electromechanical) devices were secured in Catapult supplied vests and held in place between the shoulder blades. The S7 MEMS device includes a 16g accelerometer, a 2000°•s−1 gyroscope, and 4900µT magnetometer, which are all provided at frequency of 100Hz. The S7 MEMS devices were activated at least 10 minutes prior to each data collection session for calibration and synchronisation purposes (Salazar, Ujakovic, Plesa, Lorenzo, & Alonso-Pérez-Chao, 2024). The devices remained activated until the end of the session(s) to quantify all the participants positional and external load data.

The pre-installation of the antennae, which surround sporting venues and communicate with the Catapult S7 MEMS devices, were required for the LPS data to be quantified (Rana & Mittal, 2020). 18 antennae are fitted around the University of Hull sport centre, which are positioned in optimal conditions to quantify data on any three of the futsal courts (35m x 20m). The research participants had player profiles created on the LPS online dashboard (OpenField™, Catapult Sports) before being assigned a device on OpenField™ (Catapult ClearSky S7, Catapult Sports, Melbourne, Australia: firmware version 8.1.0). The player profile characteristics included the mass (Seca 875- Scales) and height (Seca 213- Stadiometer) of the research participants. Each participant's mass and height were measured on the futsal court, at the end of the data collection period, with a stadiometer and measuring scales. The data was uploaded to the manufacturers cloud-based software (Catapult OpenField™, version 3.9.1 Build, Catapult Sports) upon completion of each data collection session. The

LPS data was quantified live, allowing the researchers to view the external load data of the participants throughout data collection and identify the timings of the sessions.

3.5 Time-Motion Analysis

The PlayerMaker™ FIMUs and Catapult ClearSky™ MEMS devices were both worn at the same time by the research participants throughout each 10-minute game of futsal match-play to monitor the participants time-motion analysis data. The two teams of five players were decided on prior to the futsal match-play sessions by the principal investigator and were made as similar as possible in each session. The time-motion analysis data quantified by Catapult ClearSky™ was monitored live by the principal investigator above the futsal court. The principal investigator had the team kicking off wait for his whistle before beginning the live time-motion analysis monitoring. The principal investigator stopped each futsal game "period" on the Catapult OpenField software when the 10-minute timer sounded on his stopwatch.

The time-motion analysis velocity thresholds (bands) were modified on the Catapult OpenField and PlayerMaker™ online dashboards to be same as each other to quantify the distance in each velocity threshold. Previous research in futsal was conducted with the sprinting threshold set to ≥ 7m/s, which would not have been achievable or appropriate for the participants in the present study (Naser, Ali, & Macadam, 2017). Even though the high-speed running (4-5 m/s) and sprinting thresholds (≥ 5m/s) were based on professional futsal, they were more appropriate for the participants in the present study (Caetano et al., 2015; Serrano et al., 2020). Due to the standard of futsal in the present study (amateur) differing to the previous research (professional), the velocity thresholds for high-speed running and sprinting had to be lowered because of the difference in physical capabilities (Freeman, Talpey, James, Opar, & Young, 2023).

The post session analysis of the open-play futsal match-play data occurred after the principal investigator uploaded the PlayerMaker™ and Catapult ClearSky™ time-motion analysis data to their respective online servers. The beginning and end time of each 10-minute game of futsal from Catapult ClearSky™ was inserted onto the online PlayerMaker™ dashboard for the data from each futsal game was the same and could be compared. The match-to-match variation of the Catapult ClearSky™ and PlayerMaker™ data of the participants who played in the most 10-minute futsal games across the data collection period were analysed.

3.6 Futsal Technical Variables

The PlayerMaker™ FIMUs and video analysis software (Catapult Vision™) were both necessary for the futsal match-play technical level of agreement to be conducted. All the futsal match-play was recorded using a camcorder (Sony HDR CX240) and tripod (Victiv 72 inches), on the balcony above the futsal court in the University of Hull Sport Centre. The camcorder video footage was recorded by the present study's principal investigator. The camcorder was started ten seconds prior to start of each futsal game and stopped recording as soon as the stopwatch reached 10 minutes and the whistle was blown.

The principal investigator created a code window on Catapult Vision™ prior to this study's data collection for the futsal technical performance data to be analysed. The Catapult Vision code window included the ball touches and ball releases of each research participant, which are quantified by the PlayerMaker™ FIMUs concurrently with the time-motion analysis data. All the ball touches and ball releases from the 26 games of futsal included within the present study's data analysis were coded by the principal investigator within the same week after a data collection session. The ball touches and ball releases data recorded by the PlayerMaker™ FIMUs were compared against the video analysis completed by the principal investigator. The match-to-match variability of the participants technical futsal performance data was also carried out for the present study.

3.7 Coder Reliability

The coder reliability within the present study was established with the principal investigator randomly selecting three 10-minute games of futsal from the present study, where the ball touches and ball releases were analysed. These three 10-minute games were analysed three times each in three weeks with the aid of two sports performance analysis interns from the University of Hull. The performance analysts were provided with the same video footage, code window, operational definitions, and information to identify the anonymised research participants. The first of the three coder reliability weeks was utilised for familiarisation and therefore the data were not included within the coder reliability results, leaving the three games to be analysed twice in the remaining two weeks.

Inter-coder reliability represents the consistency of the coding across analyses by multiple coders (Kirkwood & Sterne, 2003). A high-level of inter-coder reliability ensures for interchangeability, which will prevent a study's results being restricted to a single coder (Gwet, 2001). The inter-coder reliability of the present study was completed by utilising the Cooper, Hughes, O'Donoghue, and Nevill (2007) method. The inter-coder reliability results data were based on the final week of coding when the coders were most familiarity with the operational definitions for ball touches and ball releases. The inter-coder reliability results were also established using the coefficient of variation percentage (CV%), where the standard deviation of the mean difference between two coders was divided by the mean difference between two coders to indicate the level of dispersion between the means (Hopkins, 2000). CV% levels of agreement were displayed as good (< 5.0%), moderate (5.0% - 10.0%) or poor (> 10.0%) (Scott, Scott, & Kelly, 2016).

Intra-coder reliability is consistency of coding across analyses by the same coder (Kirkwood & Sterne, 2003). Establishing a high-level of intra-coder reliability is important for data reproducibility and the needs for scientific research to be based on concrete evidence (Gwet, 2008). This was also implemented within the present study with the Cooper, Hughes, O'Donoghue, and Nevill (2007) method and level of agreement guidelines (Scott, Scott, & Kelly, 2016) as the inter-coder reliability.

Intra-coder reliability assessed the across the second and third week of video analysis coding to allow for the principal investigator to become familiar with the operational definitions of ball touches and ball releases. The intra-coder reliability results were exhibited by a CV%, which is calculated as the standard deviation of the mean difference divided by the mean difference of a single coder.

4.0 Chapter 4: Results

4.1 Technical Performance Variables Levels of Agreement

The FIMUs quantified fewer ball releases (8.1 ± 5.9) per 10 minute futsal match on average in comparison to the video analysis (16.1 ± 5.1). The FIMUs also quantified fewer ball touches (18.5 ± 6.5) than the number of ball touches that were measured through video analysis (37.3 ± 5.3). The level of agreement between the FIMUs and video analysis for the quantification of the technical performance variables are presented in **Figure 1 (See Appendix E)** and **Figure 2 (See Appendix F)**. The number of ball releases quantified by FIMUs, and video analysis are presented in **Figure 1** and **Table 1 (See Appendix E)**. The data in the Bland-Altman plots in **Figure 1** and **Table 1** shows a poor level of agreement between the number of ball releases quantified by the FIMUs and video analysis. The ball release data quantified by the FIMUs and through video analysis are presented in **Figure 2** and **Table 2 (See Appendix F)**. The level of agreement between the FIMUs and video analysis for ball touches appears to be greater when the total number of ball touches are lower.

4.2 Intra-Coder Reliability

Table 3. A summary of the intra-coder reliability for quantifying ball releases through video analysis software.

	Match 1			Match 2			Match 3		
	CODER A	**CODER B**	**CODER C**	**CODER A**	**CODER B**	**CODER C**	**CODER A**	**CODER B**	**CODER C**
Mean Week 1	16.8	16.7	15.8	17.3	16.6	16.5	16.0	16.0	15.3
Mean Week 2	16.9	16.6	16.4	16.8	16.2	16.6	15.8	14.6	15.5
Mean Diff.	-0.1	0.1	-0.6	0.5	0.4	-0.1	0.2	1.4	-0.2
CV%	1.2	5.8	5.0	1.8	5.5	5.7	3.7	8.3	3.2
SWC	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.2	0.0

Mean Diff. = Mean Difference between coding in Week 1 and Week 2; CV% = percentage coefficient of variation; SWC = smallest worthwhile change.

Table 4. A summary of the intra-coder reliability for quantifying ball touches through video analysis software.

	Match 1			Match 2			Match 3		
	CODER A	**CODER B**	**CODER C**	**CODER A**	**CODER B**	**CODER C**	**CODER A**	**CODER B**	**CODER C**
Mean Week 1	40.4	37.2	38.5	40.8	36.3	38.1	37.8	36.5	37.2
Mean Week 2	40.1	37.5	37.2	40.6	35.7	37.8	38.7	34.1	37.1
Mean Diff.	0.3	-0.3	1.3	0.2	0.6	0.3	-0.9	2.4	0.1
CV%	2.5	4.2	6.7	2.9	5.5	3.9	2.8	6.7	3.9
SWC	0.0	0.0	0.2	0.0	0.1	0.0	0.1	0.3	0.0

Mean Diff. = Mean Difference between coding in Week 1 and Week 2; CV% = percentage coefficient of variation; SWC = smallest worthwhile change.

4.3 Inter-Coder Reliability

Table 5. A summary of the inter-coder reliability for quantifying the frequency *(f)* ball releases in video analysis software throughout 10-minute games of recreational futsal.

	Match 1			Match 2			Match 3		
	CODER A V B	**CODER B V C**	**CODER A V C**	**CODER A V B**	**CODER B V C**	**CODER A V C**	**CODER A V B**	**CODER B V C**	**CODER A V C**
Mean Diff. Week 2	0.3	0.2	0.2	0.6	-0.4	0.2	1.2	-0.9	0.3
CV%	6.6	6.3	3.3	3.0	3.7	3.3	7.3	5.7	1.5
SWC	0.2	0.2	0.1	0.1	0.1	0.1	0.2	0.2	0.0

Mean Diff. = Mean Difference between coders in Week 1 and Week 2; CV% = percentage coefficient of variation; SWC = smallest worthwhile change.

Table 6. A summary of the inter-coder reliability for the frequency *(f)* quantifying ball touches in video analysis software throughout 10-minute games of recreational futsal.

	Match 1			Match 2			Match 3		
	CODER A V B	**CODER B V C**	**CODER A V C**	**CODER A V B**	**CODER B V C**	**CODER A V C**	**CODER A V B**	**CODER B V C**	**CODER A V C**
Mean Diff. Week 2	2.6	0.3	2.9	4.9	-2.1	2.8	4.6	-3	1.6
CV%	9.4	8.6	5.3	9.2	5.0	5.9	9.3	8.3	5.5
SWC	0.7	0.5	0.4	0.7	0.4	0.4	0.7	0.5	0.4

Mean Diff. = Mean Difference between coders in Week 2; CV% = percentage coefficient of variation; SWC = smallest worthwhile change.

4.4 Time-Motion Analysis Levels of Agreement

As presented in **Table 7**, there were strong levels of agreement between the majority of the commercially available LPS (Catapult ClearSky™, Australia) and FIMUs' (PlayerMaker™, Israel) time-motion analysis variables. The only variable without a *high* (≥ 80%) level of agreement between the two systems were the sprints performed by the futsal players. The level of agreement for sprints was *moderate* (60-79.99%), with differences ($p < 0.05$) between the average number of sprints measured by the commercially available LPS (Catapult ClearSky™, Australia) and the FIMUs (PlayerMaker™, Israel).

Table 7. The level of agreement between Catapult ClearSky™ and PlayerMaker™ during 10-minute games of recreational futsal.

			Concurrent Validity			
Time Motion Analysis Variables	**ClearSky M ± SD**	**PlayerMaker M ± SD**	**Standard Error**	**Smallest Worthwhile Change**	**Pearson's Correlation Coefficient (r^2)**	**Qualitative Agreement Interpretation**
Total Distance (m)	780 ± 104	790 ± 107	20	6	0.97	***Excellent***
Relative Distance (m/min)	78 ± 10	79 ± 11	2	1	0.97	***Excellent***
Maximum Velocity (m/s)	5.3 ± 0.7	5.3 ± 0.6	0.3	0.1	0.86	***Good***
VZ1 Distance (m)	345 ± 39	369 ± 40	12	3	0.91	***Excellent***
VZ2 Distance (m)	277 ± 51	238 ± 51	10	3	0.96	***Excellent***
VZ3 Distance (m)	103 ± 40	102 ± 39	13	4	0.89	***Good***
HS Distance (m)	36 ± 22	34 ± 20	8	2	0.85	***Good***
Sprint Distance (m)	9 ± 10	7 ± 8	4	1	0.84	***Good***
Sprints	1 ± 1.1	1.7 ± 1.7	0.8	0.2	0.72	***Moderate***

M = Mean; SD = Standard Deviation; m = meters; m/s = meters per second; m/ min = meters per minute (VZ1 = Velocity Zone 1 (<1.5m/s); VZ2 = Velocity Zone 2 (1.5 – 3m/s); VZ3 = Velocity Zone 3 (3 – 4 m/s); HS Distance = High-Speed Distance (4 – 5 m/s); Sprint Distance (≥ 5m/s); Sprints (≥ 5m/s and 0.6s dwell time).

Despite the *excellent* (≥ 90%) levels of agreement between the two systems, the FIMUs quantified a greater ($p < 0.05$) total distance covered and VZ2 distance covered compared to commercially available LPS. In contrast, there was significantly more ($p < 0.05$) VZ1 distance recorded by the LPS than the FIMUs. However, there were no differences ($p > 0.05$) for maximum velocity between measuring systems even though the level of agreement between the systems was *good* (86%) instead of *excellent*. Whereas the distances covered at high speeds have a *good* (85%) level of agreement, with the LPS measuring more ($p < 0.05$) high speed distance compared to the FIMUs.

4.5 Match-to-Match Variation

The match-to-match variation and smallest worthwhile change results of the external load and technical performance variables are presented in **Table 8** and **Table 9**, respectively. The external load metrics CV values ranged from 5.3% to 13.3%, with the lowest CVs corresponding to the maximum velocity data (5.7-10.5%) quantified by the FIMUs. However, the external load metric with the highest variation was the relative distance quantified by the FIMUs (13.3%) and the LPS (13.1%). Player 5 demonstrated the least variation in their external load data from the present study for all four metrics (distance per minute and maximum velocity quantified by the FIMUs and the LPS) (5.7-8%) in **Table 8**. Whereas player 3 had the highest variation in their external load data (10.6-13.3%). Among the external load data from all in 10 players in the match-to-match variation analysis, the commercially available LPS had less variation (9.6%) than the FIMUs (9.9%) for quantifying relative distance covered. On the other hand, the variation of the maximum velocity quantified by the FIMUs (7.6%) was lower than the maximum velocities quantified by the LPS (9.6%).

In contrast, the technical performance variables CVs ranged from 6.9% to 100%. The technical performance variable with the lowest variation is ball touches (6.9-40.0%), quantified through the video analysis software. The ball touches quantified by the FIMUs (37.5-100.0%) had the highest variation of all four of the technical performance variables. Player 5 also had the lowest variation in their technical performance variables (17.6-50.0%) across the present study. The participant with the most variation in their technical performance data (19.4-100.0%) was player 8.

The technical performance variables presented in **Table 2** showed that the ball touches quantified by the FIMUs had a smaller variation across all the players (21.1%) in comparison to the ball touches quantified through video analysis (28.9%). The **Figure 2** Bland-Altman plot shows that the greater the number of ball touches recorded by both measuring systems, the greater level of discrepancy between systems. Whereas the ball releases, presented in **Table 1**, recorded by the FIMUs had greater variation (37.5%) across the 10 players in the match-to-match variation analysis than the ball releases recorded through video analysis (17.6%).

Table 8. Match-to-match variation of the time-motion analysis variables throughout 10-minute games of recreational futsal.

Player	Player 1	Player 2	Player 3	Player 4	Player 5	Player 6	Player 7	Player 8	Player 9	Player 10	ALL PLAYERS
Number of Match Observations	**26**	**24**	**24**	**23**	**22**	**22**	**20**	**16**	**14**	**12**	**203**
Relative Distance (m.min) (PlayerMaker)											
Mean ± SD	76.7 ± 7.2	85.8 ± 11.4	75.2 ± 10.0	68.7 ± 7.0	87.9 ± 6.6	85.6 ± 5.8	63.4 ± 5.1	76.2 ± 4.1	80.1 ± 7.0	84.8 ± 8.8	78.5 ± 7.7
% CV	9.1	12.8	13.3	10.1	8.0	7.0	7.9	5.3	8.8	10.6	9.9
SWC %	1.4	2.2	2.0	1.4	1.4	1.2	1.0	0.8	1.4	1.8	1.5
Relative Distance (m.min) (ClearSky)											
Mean ± SD	76.5 ± 7.5	84.1 ± 10.7	77.4 ± 9.7	66.7 ± 6.3	85.8 ± 6.1	84.7 ± 5.4	62.4 ± 5.9	77.4 ± 3.1	78.2 ± 6.5	83.3 ± 7.5	77.6 ± 7.4
% CV	10.4	13.1	13.0	9.0	7.0	5.9	8.1	3.9	9.0	9.6	9.6
SWC %	1.6	2.2	2.0	1.2	1.2	1.0	1.0	0.6	1.4	1.6	1.5
Maximum Velocity (m/s) (PlayerMaker)											
Mean ± SD	5.5 ± 0.4	5.7 ± 0.4	5.7 ± 0.6	4.4 ± 0.3	5.3 ± 0.3	5.5 ± 0.5	5.0 ± 0.5	5.3 ± 0.4	4.8 ± 0.5	5.2 ± 0.4	5.2 ± 0.4
% CV	7.3	7.1	10.5	6.8	5.7	9.2	9.9	7.6	10.4	7.7	7.6
SWC %	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Maximum Velocity (m/s) (ClearSky)											
Mean ± SD	5.6 ± 0.4	5.8 ± 0.6	5.7 ± 0.6	4.4 ± 0.4	5.0 ± 0.4	5.7 ± 0.6	4.5 ± 0.6	5.3 ± 0.5	4.8 ± 0.4	5.4 ± 0.4	5.2 ± 0.5
% CV	7.1	10.4	10.6	9.5	8.0	10.6	13.2	9.4	8.4	7.4	9.6
SWC %	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Table 9. Match-to-match variation of the frequency *(f)* of ball touches and ball releases throughout 10-minute games of recreational futsal.

Player	Player 1	Player 2	Player 3	Player 4	Player 5	Player 6	Player 7	Player 8	Player 9	Player 10	ALL PLAYERS
Number of Match Observations	**26**	**24**	**24**	**23**	**22**	**22**	**20**	**16**	**14**	**12**	**203**
Ball Touches (PlayerMaker)											
Mean ± SD	14 ± 2	18 ± 8	18 ± 5	17 ± 5	17 ± 3	29 ± 9	16 ± 4	15 ± 3	22 ± 6	21 ± 4	19 ± 4
% CV	14.3	44.4	27.8	29.4	17.6	31.0	25.0	20.0	27.3	19.0	21.1
SWC %	0.4	1.6	1.0	1.0	0.6	1.8	0.8	0.6	1.2	0.8	0.8
Ball Touches (Video Analysis)											
Mean ± SD	29 ± 2	35 ± 10	33 ± 5	34 ± 7	37 ± 8	67 ± 22	33 ± 7	31 ± 6	37 ± 7	40 ± 6	38 ± 11
% CV	6.9	40.0	15.2	20.6	21.6	32.8	21.2	19.4	18.9	15.0	28.9
SWC %	0.4	2.0	1.0	1.4	1.6	4.4	1.4	1.2	1.4	1.2	2.2
Ball Releases (PlayerMaker)											
Mean ± SD	7 ± 5	10 ± 5	12 ± 8	7 ± 5	10 ± 5	4 ± 5	6 ± 4	5 ± 5	9 ± 5	12 ± 9	8 ± 3
% CV	71.4	50.0	66.7	71.4	50.0	80.0	66.7	100.0	55.6	75.0	37.5
SWC %	1.0	1.0	1.6	1.0	1.0	1.0	0.8	1.0	1.0	1.8	0.6
Ball Releases (Video Analysis)											
Mean ± SD	16 ± 5	15 ± 5	17 ± 7	14 ± 5	16 ± 4	18 ± 5	18 ± 3	14 ± 5	14 ± 3	24 ± 7	17 ± 3
% CV	31.3	33.3	41.2	35.7	25.0	27.8	16.7	35.7	21.4	29.2	17.6
SWC %	1.0	1.0	1.4	1.0	0.8	1.0	0.6	1.0	0.6	1.4	0.6

5.0 Chapter Five: Discussion

The objectives of the study were: 1) To compare the level of agreement between the time-motion analysis data of FIMUs (PlayerMaker, Israel) and a local positioning system (Catapult ClearSky, Australia); 2) To establish analyse the level of agreement between the FIMUs (PlayerMaker, Israel) and video analysis software for the quantification of the technical performance variables of futsal. This is important because it could identify systematic errors in the FIMU data, which could improve the accuracy of the data quantified by the system (Anwary, Yu, Callaway, & Vassallo, 2020). In addition, comparing the FIMU data to the established methods for quantifying time-motion and technical performance data will provide sporting practitioners with assurance that the data being recorded by the FIMU system is accurate and comparable (Malone, Lovell, Varley, & Coutts, 2017).

The main findings of this study were: (1) there was an *excellent* ($p < 0.05$) level of agreement between the LPS (mean ± SD = 780 ± 104 m; range = 510 – 987 m) and FIMUs (mean ± SD = 790 ± 107 m; range = 489 – 1023 m) for the quantification of distance covered; (2) maximum velocity displayed a *good* ($p > 0.05$) level of agreement between the LPS (mean ± SD = 5.3 ± 0.7 m/s; range = 3.8 - 7.1 m/s) and FIMUs (mean ± SD = 5.3 ± 0.6 m/s; range = 3.7 - 7.3 m/s) despite having small mean differences and standard deviations; (3) the level of agreement between the FIMUs (mean ± SD = 8 ± 6; range = 0 – 29 n) and video analysis coding (mean ± SD = 16 ± 5 n; range = 4 – 34 n) was *poor* ($p < 0.05$) for the quantification of ball releases; (4) although the level of agreement for the quantification of ball touches was higher than ball releases, there was a *weak* ($p < 0.05$) level of agreement between the FIMUs (mean ± SD = 18 ± 7 n; range = 11 – 44 n) and the video analysis coding (mean ± SD = 37 ± 14 n; range = 24 – 99 n); (5) the time-motion analysis variables (Relative Distance and Maximum Velocity) had a lower variation (% CV range = 3.9 - 13.3%) across the results within this study compared to the technical performance variables (Ball Releases and Ball Touches) (% CV range = 6.9 - 100%).

5.1 Time-Motion Analysis Level of Agreement between Systems

Data presented in **Table 5** shows that the distance covered as quantified by the LPS and FIMUs had *excellent* levels of agreement. Although the PlayerMaker™ FIMUs had not been previously compared against an LPS, the findings in the present study are corroborated by previous researchers who have compared the time-motion data of the LPS against the Vicon motion capture system (Serpiello et al., 2017). The total distance covered data of both systems had mean differences between 0.2 and 2.3% (Serpiello et al., 2017). The results of the present study and the Serpiello et al. (2017) study could have been similar as both studies utilised the same local positioning system (ClearSky™) for quantifying time-motion data against another measuring system. Despite the differences between the FIMUs and Vicon, both systems are dependent on precise data collection and processing algorithms to quantify time-motion data (Waldron, Harding, Barrett, & Gray, 2020).

It is also possible that there was an *excellent* level of agreement between the LPS and FIMUs for total distance covered because the MEMS devices from both systems include a 3D accelerometer and a gyroscope to measure the accelerations in three different axes and the angular velocity (Waldron, Harding, Barrett, & Gray, 2020; Catapult, 2023). The accelerometers in the MEMS devices of both systems could contribute to the total distance covered level of agreement in the present study because accelerometers quantify movement by measuring changes in speed and direction (Muset & Emerich, 2012). Whereas gyroscopes could be a reason for the *excellent* level of agreement for total distance covered because they measure the orientation and rotational movements of the MEMS devices (Muset & Emerich, 2012). Therefore, the similar technology within the MEMS devices of both systems could have contributed to the *excellent* levels of agreement for total distance covered between the FIMUS and LPS in the present study.

. As hypothesised, there was a strong level of agreement between the FIMUs and the LPS for measuring total distance. However, the FIMUs also quantified greater total distance covered compared to the LPS in the present study. These findings are mirrored by previous research showing that FIMUs measure significantly higher total distance covered (518 ± 15 m) than three different GPS systems (488 ± 15 m; 486 ± 15 m; 501 ± 14 m) (Waldron, Harding, Barrett, & Gray, 2020). The results of the present study and Waldron et al. (2020) were potentially similar because a network of sensors is required for an LPS (transmitters and receivers) and GPS (satellites) to quantify the time-motion analysis data (Rico-González, Los Arcos, Clemente, Rojas-Valverde, & Pino-Ortega, 2020). Additionally, local positioning systems and global positioning systems utilise positional differentiation to quantify distance covered parameters (Hoppe, Baumgart, Polglaze, & Freiwald, 2018). It was hypothesised that the FIMUs would measure a greater total distance compared to the LPS because of the anatomical placement of the FIMUs being able to detect the movement of the lower limbs more accurately than the MEMS devices worn on the upper body (Barrett et al., 2016). Such differences including sampling frequency may have attributed to the FIMUs measuring a higher total distance covered than the LPS as the FIMUs have a higher sampling frequency (1000Hz) in comparison to the LPS MEMS devices (10Hz). The sampling frequency of both measuring systems could have affected the total distance recorded because higher sampling frequencies of MEMS devices increases the precision of the quantified data and reducing the possibility of data not being recorded by the MEMS devices (Kavanagh & Menz, 2008).

In contrast, the LPS overestimated the total distance covered compared to the actual distance measured by a criterion system in previous research, with overestimation potentially occurring due to the indoor conditions (Luteberget, Spencer, & Gilgien, 2018). The indoor conditions could cause an overestimation in total distance covered because of the metallic structures that can cause signal interference and fluctuations in the data (Tiku & Pasricha, 2023). However, in another study total distance covered was underestimated by the LPS (0.2 – 12% mean difference) (Serpiello et al., 2017). The underestimation of total distance covered by the LPS in the Serpiello et al. (2017) study was a result of the removal of data where step to step fluctuations in velocity occurred. Therefore, the estimation of the total distance covered in these previous studies could have been affected by the sampling frequency of the LPS, which was 20Hz in the Luteberget, Spencer, and Gilgien (2018) study, whereas the sampling frequency of the LPS in the Serpiello et al. (2017) study was 10Hz. The lower sampling frequency could have led to the underestimation of total distance covered in the Serpiello et al. (2017) study because an LPS with a lower sampling frequency quantifies fewer data points per second (Hoppe, Baumgart, Polglaze, & Freiwald, 2018). Therefore, the LPS MEMS devices with a lower sampling frequency may fail to record small, sharp movements, and changes of direction (Hoppe, Baumgart, Polglaze, & Freiwald, 2018).

Table 5 includes the maximum velocity data measured by the LPS and the FIMUs. In contrast to the hypothesis, where it was stated that there would be a clear difference in the maximum velocity recorded by both measuring devices, there were *good* levels of agreement between the two measuring devices for maximum velocity. Previous research has shown that there was a small mean difference of 0.2 – 12% between the LPS and Vicon for the measurement of maximum velocity (Serpiello et al., 2017). Even though Luteberget, Spencer, and Gilgien (2018) explained that there were significant differences in the velocities measured by ClearSky™ and Qualisys, these differences were velocity dependent. The differences were velocity dependent because high velocity movements cause more vibrations and shock on the MEMS devices, leading to a greater amount of noise in the velocity data quantified by the MEMS devices (Skogström, Mattila, & Vuorinen, 2020). The results of Luteberget et al. (2018) showed that discrepancies between the Catapult ClearSky™ and Qualisys velocity data began to occur when the LPS MEMS devices achieved a velocity > 3m/s. This could have occurred because LPS MEMS devices experience the accumulation of errors over long periods of time (drift) (Zhang et al., 2021). Drift could occur because of the materials and electronic components of MEMS devices deteriorating with use, which decreases the accuracy of the velocity data quantified by the MEMS devices (Dutta & Pandey, 2021). This is related to findings in the present study because the MEMS had been previously used for sports performance outside of the present study. Furthermore, it would be difficult for any individuals to have the physical capability to achieve a high maximum velocity due to the limited playing area of a futsal court (Ribeiro et al., 2023). Therefore, any differences in the device agreement for maximum velocity could be a causal factor due to the small number of sprints that were performed throughout the current study's futsal match-play. Henceforth, why the external validity of maximum velocity was not measured in the present study.

The level of agreement between the LPS and the FIMUs for measuring maximum velocity is further supported by previous research regarding the FIMUs (Myhill, Weaving, Robinson, Barrett, & Emmonds, 2023; Sandmæl & Dalen, 2023). The FIMUs comparison to the Qualisys criterion reference system demonstrated a *good* level of agreement (Myhill, Weaving, Robinson, Barrett, & Emmonds, 2023). The research of Myhill et al. (2023) showed that the FIMUs underestimated the actual maximum velocity when compared to the criterion system, with an overall mean difference of 0.048 ± 0.581m/s. In addition, the comparison between the FIMUs and three different commercially available GPS devices showed no significant difference to mean differences for measuring maximum velocity (Waldron, Harding, Barrett, & Gray, 2020). However, GPS#1 and GPS#2 recorded higher maximum velocity mean differences than the FIMUs (0.3 ± 0.71m/s; 0.12 ± 0.41m/s). Whereas GPS#3 had lower mean difference value for maximum velocity (0.09 ± 0.4m/s) when compared to the FIMUs. These insignificant mean differences when measuring maximum velocity between the FIMUs compared to the GPS devices and Qualisys explains why there is no difference to the maximum velocity means in the present study.

The present study found that total distance covered in lower velocity thresholds quantified by the LPS and the FIMUs had an *excellent* level of agreement. Although Luteberget, Spencer, and Gilgien (2018) did not attempt to quantify total distance covered within different velocity zones, they observed high levels of agreement between LPS and Qualisys for velocities measured up to 3 m/s within optimal conditions. This could have been because the LPS MEMS devices have a lower sampling frequency in comparison to the criterion reference system, preventing the LPS from being unable to quantify velocity data as frequently as the reference system (Hoppe, Baumgart, Polglaze, & Freiwald, 2018). In addition, Luteberget, Spencer, and Gilgien (2018) observed a low number of errors between the LPS and the criterion system (Qualisys) for distance covered, with a mean difference of 0.5 and

1.8% in optimal conditions. This might be because an UWB LPS is less susceptible to interference from other frequencies and can pass through most objects (Alarifi et al., 2016). These findings demonstrate that there is *excellent* level of agreement for total distance covered at lower velocities in the present study because UWB LPS MEMS devices have a large bandwidth that makes the LPS more resistant to multi-path interferences (Aiello, & Batra, 2006). Whereas the FIMUs use a combination of in-built sensors rather than a reference system to quantify time-motion analysis data and are therefore not affected by signal interference (Waldron, Harding, Barrett, & Gray, 2020).

Despite the *excellent* level of agreement between the LPS and the FIMUs, there were significant mean differences (24m) in the VZ1 threshold for total distances covered. Although Waldron, Harding, Barrett, and Gray (2020) validated the time-motion analysis variables of the FIMUs against three different GPS devices and their results included the distances covered within lower velocity thresholds. Even though the velocity zone one threshold (< 1.5 m/s) was identical to the present study, all three GPS devices in the Waldron et al. (2020) study measured a greater total distance covered in the velocity zone one than the FIMUs (29.14 ± 17.26m; 18.99 ± 17.28m; 27.77 ± 7.16m). This could have been because the positional updates of a GPS are more frequent at lower velocities due to the smaller distances between signals (Hofmann-Wellenhof, Lichtenegger, & Wasle, 2008). Whereas the FIMUs in present study recorded a greater total distance covered in velocity zone one. The significant mean difference (24m) in the present study when measuring total distance covered in velocity zone one could have occurred because the FIMUs have a higher sampling frequency than the LPS MEMS devices, allowing them to quantify more data per second including smaller movements at lower velocities (Hoppe, Baumgart, Polglaze, & Freiwald, 2018).

The LPS and FIMUs have a *good* level of agreement for total high-speed distance and sprinting distance. However, the LPS quantified a greater amount of total amount of high-speed distance than the FIMUs. Although Waldron, Harding, Barrett, and Gray (2020) have partially different high-speed (3.51 – 5.5m/s) and sprinting (> 5.5m/s) distance covered thresholds, the mean differences across these two variables show a strong level of agreement when comparing the FIMUs to the three different GPS devices. In contrast to the present study, the FIMUs measured a greater total high-speed distance covered compared to the three different GPS devices (29.06 ± 29.41; 21.39 ± 25.41; 23.31 ± 27.15) (Waldron, Harding, Barrett, & Gray, 2021). Two of the three GPS MEMS devices in the Waldron, Harding, Barrett, and Gray (2020) study had the same sampling frequency (10Hz) as the LPS MEMS devices in the present study. Therefore, the sampling frequency of the MEMS devices could have been a reason for the *good* level of agreement between the LPS and FIMUs for high-speed distance and sprinting distance.

Despite the insignificant mean differences, the level of agreement for high-speed distance and sprinting distance between the LPS and FIMUs in the present study was *good*. Luteberget, Spencer, and Gilgien (2018) identified that velocity errors occurred within the LPS MEMS devices at velocities > 3m/s. This could be result of the metallic structures and increased environmental temperatures indoors causing signal interference to the LPS (Alarifi et al., 2016). The UWB signals emitted by the LPS reflect off indoor structures and the presence of other electronic device signals can cause multipath interference and the possibility of increased mean errors ranges to occur (Alarifi et al., 2016). Leser, Schleindlhuber, Lyons, and Baca's (2014) findings showed that the LPS has mean error ranges of the 2.0 to 3.5% when recording time-motion analysis variables. Small mean error ranges between the LPS and a criterion reference system is relevant as it enhances the precision of the data quantified by the LPS used in the present study (Hopkins, Marshall, Batterham, & Hanin, 2009). Despite the insignificant mean differences within the present study for high-speed distance and sprinting distance, the velocity errors measured by the LPS could have caused a decrease in the level of agreement for distance covered at higher velocities .

The *moderate* level of agreement for sprint efforts between the LPS and the FIMUs could have been affected by the dwell time (or minimum effort duration) of the sprint effort. Previous research has shown that dwell times could cause data errors throughout the quantification of effort-based time-motion analysis metrics (Scott, Scott, & Kelly, 2016; Varley, Jaspers, Helsen, & Malone, 2017). Despite both measuring systems in the present study having a sprint dwell time of 0.6 seconds, higher dwell times may cause the measuring systems to underestimate the number of sprint efforts (Varley, Jaspers, Helsen, & Malone, 2017). Although Varley, Jaspers, Helsen, and Malone (2017) assessed the level of agreement of sprint efforts between two different global positioning systems, dwell time was responsible for more and bigger differences in the number of sprint efforts quantified by both systems. The quantification of distance covered within velocity thresholds is seen as a more suitable alternative to measuring high velocities over the number of velocity-based efforts (Varley, Jaspers, Helsen, & Malone, 2017). Varley, Jaspers, Helsen, and Malone (2017) emphasised the use of distance covered within velocity thresholds over a sprint effort count because the greater the dwell time for sprint efforts, the fewer the number of sprint efforts will be quantified by the measuring systems. Therefore, the errors at high velocities in the data outputs of the LPS and the dwell times in the present study could have caused there to be disagreement in the quantified sprint efforts.

5.2 Technical Performance Level of Agreement between Systems

The level of agreement between the FIMUs and the video analysis coding for the quantification of ball touches and ball releases was inferior to that which was found for the time-motion analysis variables. The Bland-Altman plot in **Figure 1** showing the *poor* level of agreement between the FIMUs and video analysing coding for measuring ball releases could be due to the instability of the FIMUs on the footwear of the present study's research participants. Despite the FIMUs being used for futsal and on flat soled shoes in the present study, the FIMUs were designed to be worn on football boots (Waldron, Harding, Barrett, & Gray, 2020). The studs on the bottom of football boots allow for the FIMUs to be fixated and be restricted to limited movement on the boot (Waldron, Harding, Barrett, & Gray, 2020). Previous research shows that IMUs need to be fixated on the body or the IMUs orientation in space cannot be estimated (Kamstra, Wilmes, & Van der Helm, 2022). However, the footwear and the playing surface within the present study resulted in the FIMUs moving on the footwear of the participants throughout futsal match-play. Consequently, the movement of the FIMUs on the footwear of the participants throughout futsal match-play could contribute to the lack of agreement between the ball releases quantified by the FIMUs and the video analysis coders.

The signal quality and measurement noise of the FIMUs could also be a factor for the lack of agreement between the FIMUs and video analysis coding for measuring the ball releases in the present study. The measurement noise could have been a contributing factor to the lack of agreement due to it being a common issue within inertial measurement technology (Liu, Peng, Tong, Yang, & Liu, 2018). Noise could be caused by extrinsic factors including impacts from other people or objects and interference from electronic devices (Tanner et al., 2000; White et al., 2000). As the PlayerMaker™ FIMUs use a custom-built machine learning algorithm to detect and quantify technical load (Waldron, Harding, Barrett, & Gray, 2020), the noise could have increased and negatively affected the algorithm due to the movement of the FIMUs on the participant's footwear (Cheung et al., 2019). Furthermore, previous research has ensured that FIMUs are fixed in place when aiming to establish the concurrent validity of the device for quantifying ball releases (Marris, Barrett, Abt, & Towlson, 2022). Therefore, the fixation of the FIMUs would see less noise and an increase signal quality, which could have led to a greater level of agreement between the ball releases quantified in futsal by the FIMUs and through video analysis.

The level of agreement between both measuring systems for measuring ball touches and ball releases could because futsal is a highly technical sport which requires the players to keep the ball close to their feet (Naser, Ali, & Macadam, 2017). This could have led to false positives or false negatives being measured in the video analysis or by FIMUs (Almajai et al., 2012). These can occur throughout video analysis due to video footage being two dimensional and the vantage points for filming being limited. Therefore, it could have been more difficult to identify smaller touches completed by the futsal players during the video analysis. However, neither video analysis or the FIMUs are criterion measures for analysising the technical variables of futsal. Furthermore, the coder reliability analysis in the present study showed a good level of agreement, which is a simple method that can be applied to video analysis studies.

The level of agreement between the FIMUs and video analysis coding for the quantification of ball touches as shown in **Figure 2**. Despite the low level of agreement between the two methods for the quantification of ball touches in futsal, there was a greater level of agreement between the two systems for ball touches than there was for ball releases. This could be a result of less movement by the FIMU on the footwear of the participants when a ball touch was performed. There could have been less movement by the FIMUs whilst ball touches were performed because futsal requires the players to gently manipulate the ball due to the small dimensions of the playing area (Araújo, Davids, Bennett, & Button, 2004). In contrast, ball releases in futsal require an increase in movement and speed (Egan, Verheul, & Savelsbergh, 2007), which could have caused the FIMUs to move more than when they were fixated on football boots in previous research when quantifying ball touches (Marris, Barrett, Abt, & Towlson, 2022). Affixing the FIMUs to the footwear of futsal players could see a greater level of agreement between the FIMUs and video analysis for ball touches. This is speculated because there could be a decreased amount of noise if the FIMUs are fixated to the footwear of futsal players and other codes of football for match-play and training due to the restriction of FIMU movement. In addition, the affixation of the FIMUs to the footwear of the athletes would be beneficial as it would take away the possibility of the silicone straps sliding on the footwear.

Furthermore, the comparison between the FIMUs and video analysis coding for measuring ball touches does not show a satisfactory level of agreement. Similarly to ball releases, the signal and noise could have been a contributing factor for the level of discrepancy between the FIMUs and the video analysis coding as signal noise has caused problems within previous research analysing IMUs (Napier, Willy, Hannigan, McCann, & Menon, 2021). Signal quality and noise are important when quantifying machine learning data as they can affect the accuracy of the data (Chen, Xia, Zhao, Fu, & Chen, 2024). Poor signal quality and increased noise could occur due to impacts on the MEMS devices and negatively affect the accuracy of machine learning data (Biju, Schmitt, & Engelmann, 2024). Therefore, the noise could lead to distortions in the data quantified by machine learning devices as they rely on high-quality signals for greater data accuracy (Biju, Schmitt, & Engelmann, 2024). This means that sporting practitioners should be mindful of the limitation the current study has raised. Specifically, practitioners involved in sports with flat bottom soles should be considerate of the amount of noise that some technologies, such as PlayerMaker™. Therefore, the technology used to quantify sports performance data should be chosen based on the environment it is being used in. This could be the case for PlayerMaker™ as the FIMUs are validated in football, but it doesn't mean that that they are the appropriate technology for quantifying the technical variables of futsal.

5.3 Match-to-Match Variation of Time-Motion & Technical Performance Variables

This is the first study to analyse the match-to-match variability of the physical and technical variables in futsal using LPS and FIMU technology. There is limited existing literature on match-to-match variation on physical futsal performance (Riberio et al., 2021). However, researchers have emphasised the importance of distance covered per minute in futsal instead of total distance covered to quantify the intensity of athletic performance (Riberio et al., 2021). Across all the players within this study, distance per minute was similarly variable when measured by the FIMUs (CV = 9.9%; SWC = 1.5%) and LPS (CV = 9.6%; SWC = 1.5%). The similar levels of variability measured by the FIMUs and LPS occurred due to the excellent level of agreement between the two systems for relative distance covered. However, the raw SWC relative distance values derived from the FIMUs (1.8 m.min) and LPS (1.6 m.min) across all players within the study can reveal where fatigue may have onset during futsal match-play (Naser, Ali, & Macadam, 2017). Despite the contextual factors in futsal, such as playing position and minutes played (Spyrou, Freitas, Marín-Cascales, Herrero-Carrasco, & Alcaraz, 2021), increases in relative distance throughout futsal match-play could suggest an improvement in the players' aerobic fitness (Dal Pupo, Barth, Moura, & Detanico, 2020). The individualisation of the SWC to relative distance would provide a more specific insight to the intensity each player has played at across multiple matches played (Naser, Ali, & Macadam, 2017).

The ability to repeatedly perform actions at high speeds (≥ 5.1 m/s) in (professional) futsal has been previously identified as a key performance indictor for successful performance (Barbero-Alvarez, Soto, Barbero-Alvarez, & Granda-Vera, 2008; Oliveira, Leicht, Bishop, Barbero-Alvarez, & Nakamura, 2013). The LPS (9.6%) had a greater amount of match-to-match variation in comparison to the FIMUs (7.6%) for maximum velocity across all players in the present study, which shows the potential errors that can occur when the ClearSky™ LPS quantifies higher velocities (Luteberget, Spencer, & Gilgien, 2018). This is an issue for sporting practitioners because the velocity data the devices quantify could be inaccurate and therefore affect the physical conditioning decisions of the sporting practitioners (Malone, Lovell, Varley, & Coutts, 2017). The raw CV and SWC values for maximum velocity (m/s) measured by the FIMUs (0.4; 0.05) and LPS (0.5; 0.05) across all players in the present study showed little variability in the maximum velocities achieved by the participants. It is plausible to suggest that the reduced futsal court dimensions limited the maximum velocity that players can achieve throughout match-play (Ribeiro et al., 2024), the maximum velocities reached by the elite futsal players competition are greater in velocity due to physical demands of elite futsal competition (Naser & Ali, 2016). Even though there was little variability in the maximum velocities reached throughout the study, variables more specific to the demands of futsal could have shown more meaningful SWCs.

The technical demands of futsal are viewed as a more influential key performance indicator to success in match-play than the physical demands of futsal (Ribeiro et al., 2020). The unlimited substitution rule in official futsal match-play could decrease the importance of the physical variables required for futsal (Serrano et al., 2020). The raw variability and SWC values of the ball touches recorded by all players are higher for video analysis (11; 0.8) than for the FIMUs (4; 1.5). These results reveal the discrepancy between the two measuring systems for ball touches. The variability of each player's number of ball touches shows the amount of technical involvement that they have across matches (Mendes et al., 2022). Futsal players are exposed to ball touches frequently throughout match-play due to the limited court dimensions and players on the court (Mendes et al., 2022). However, each player's number of ball touches is dependent on several contextual factors including playing position and game state (Palucci Vieira et al., 2021). These factors are important for futsal players because they may need additional exposure to a game-specific amount of ball touches if they have not played many minutes on the court or had much possession of the ball (Castagna, D'Ottavio, Vera, & Álvarez, 2009). On the other hand, a higher intensity futsal match could involve a greater number of ball touches (Castagna, D'Ottavio, Vera, & Álvarez, 2009). Therefore, futsal players may require additional exposure to ball touches as preparation for their next involvement in futsal performance or carry out an appropriate recovery process to maintain their optimal physical condition (Castagna, D'Ottavio, Vera, & Álvarez, 2009).

A variety of futsal ball kicking actions, including passes and shots, can be quantified as a ball release (Hermans & Engler, 2010). However, the raw variability and SWC values of ball releases recorded by "all players" were similar between video analysis (3; 1) and the FIMUs (3; 0.5). The FIMUs have a greater level of variation (CV%) across the study for ball releases (37.5%) in comparison to the video analysis coding (17.6%). The results of the ball releasing actions in amateur futsal shows a high level of discrepancy between both measuring systems. However, the lack of raw variability between the ball releases quantified across the study reveals the importance each player can have on futsal match outcome (Palucci Vieira et al., 2021). The number of ball releases in futsal match-play is dependent on the execution of each player's ball releases, each team's speed of play with the ball, and how each team defends without the ball (Méndez-Dominguez, Nakamura, & Travassos, 2022). Therefore, the variation of ball releases in the present study could also have been affected by the contextual factors of futsal match-play, such as the scoreline (Méndez-Dominguez, Nakamura, & Travassos, 2022). These contextual factors are also important for ball releases as futsal players require adequate exposure to ball releases, such as passes, due to maintain technical performance if they do not achieve enough during match-play (Castagna, D'Ottavio, Vera, & Álvarez, 2009). Furthermore, the contextual factors may cause an over exposure to ball releases, requiring the futsal players to use appropriate recover methods to reduce potential injury risk (Castagna, D'Ottavio, Vera, & Álvarez, 2009). Therefore, the quantification of technical load is paramount for assessing the exposure that futsal players have had during match-play as they may require additional exposure or recovery to maintain performance (Castagna, D'Ottavio, Vera, & Álvarez, 2009).

6.0 Chapter 6: Conclusion

This study aimed to analyse the level of agreement between a commercially available LPS (Catapult ClearSky™, Australia) and FIMU (PlayerMaker™, Israel). This descriptive, cross-sectional study showed that there are *strong* ($p < 0.05$) levels of agreement for the time-motion analysis variables between the LPS (M ± SD = 780 ± 104 m; range = 510 – 987 m) and the FIMUs (M ± SD = 790 ± 107 m; range = 489 – 1023 m). The FIMUs measured a greater total and relative distance covered than the LPS, despite the difference being minute. It is plausible to suggest that this was due to the anatomical placement (lateral malleoli) and higher sampling frequency (1000 Hz) of the FIMUs (Sandmael & Dalen, 2023). Even though the FIMUs have previously underestimated maximum velocity at high velocities (Myhill, Weaving, Robinson, Barrett, & Emmonds, 2023), the maximum velocity parameter has *good* ($p < 0.05$) levels of agreement between the two wearable devices in the present study. Therefore, it is recommended that the FIMUs are utilised as a cheaper alternative than an LPS for the quantification of time-motion analysis data indoors.

The purpose of this study was also to analyse the level of agreement between the FIMUs and video analysis for the technical variables of futsal. However, the results show there to be *poor* levels of agreement between the two systems for quantifying ball touches and ball releases in futsal match-play. Such findings could have been due to the FIMUs having been worn on flat soled shoes, when the silicone straps were designed to be held in place by the studs of football boots and held in place on the lateral aspect of calcanei (Waldron, Harding, Barrett, & Gray, 2020). This study provides cautionary evidence that video analysis methods provide a more suitable way of measuring technical variables of futsal due to impact of noise on the FIMUs when technical performance data is quantified.

Finally, this study analysed the match-to-match variation of the research participant's time-motion analysis and technical futsal performance data. The match-to-match variability of the time-motion data showed the least amount of variation across the present study, with no coefficient of variation above 13.3% for distance covered and maximum velocity. Whereas the technical futsal variables showed the highest variability across the match-to-match variation data, with all but one player having a coefficient of variation greater than 10%. Therefore, it is recommended that futsal practitioners utilise the match-to-match variability of time-motion analysis variables to identify any changes to each player's physical performance in futsal match-play. Whereas the analysis of technical futsal actions should be completed by futsal practitioners to identify strengths and areas for improvement of each futsal team and player.

6.1 Limitations

Although the present study aimed to analyse the level of agreement between the FIMUs and an LPS, there was no gold standard motion capture reference system in place to obtain the actual time-motion analysis data. The inclusion of a reference system would have revealed whether the data quantified by the LPS or the FIMUs were closer to the actual time-motion analysis data. However, the FIMU time-motion analysis data has been compared concurrently against a motion capture reference system in previous research on flat soled shoes in multiple locomotor activities (Myhill, Weaving, Robinson, Barrett, & Emmonds, 2023). The criterion reference system markers would have also been required to be worn on the footwear of the participants throughout the present study and could have been affected by the foot to foot or ball to foot contact throughout the futsal match-play.

Signal noise is a limitation of the current study due to the other wireless devices being present next throughout the data collection process. Wireless devices, such as smart phones, emit electromagnetic signals that could affect the precision of the data quantified by an LPS (Brunner, Stocker, Schuh, Schuß, Boano, & Römer, 2022). This is due to the signals of multiple wireless devices overlapping when they are present in the same environment (Brunner, Stocker, Schuh, Schuß, Boano, & Römer, 2022). The interference caused by the presence of other electronic equipment could affect the LPS's ability to accurately track the distances and velocities achieved by the participants in the present study (Clemente, Pino-Ortega, & Rico-González, 2021). This was not a consideration at the time of data collection as the LPS in the present study is less prone to interference from other electrical devices due to its larger frequency bandwidth (Mannay, Benhadjyoussef, Machhout, & Urena, 2016). it is recommended the presence of additional wireless devices throughout data collection is limited to minimise signal overlapping.

Multipath propagation would have occurred within the data collection venue as the futsal court was indoors, causing the LPS MEMS device signals to bounce of walls and structures of the building before reaching the antenna (Sathyan, Shuttleworth, Hedley, & Davids, 2012). This is a limitation of the present study because the signals emitted from the LPS MEMS devices have to take a longer and indirect route to reach the antenna (Sathyan, Shuttleworth, Hedley, & Davids, 2012). A longer signal route to the antenna could lead to errors in the positional calculations and affect the accuracy of the LPS data (Muthukrishnan, 2009). Future researchers should consider the possibility that multipath propagation could affect the LPS data's level of precision when indoors. The present study is limited as it was not able to compare the acceleration and deceleration levels of agreement between the LPS and the FIMUs. Accelerations and decelerations are futsal specific due to the sport's dynamic nature and worthy of further investigation in the various levels of futsal competition (Ribeiro, Monteiro, Gonçalves, Brito, Sampaio, & Travassos, 2021; Ribeiro, Farzad, Illa, Ferraz, Nakamura, & Travassos, 2024). As futsal is played within a smaller playing area compared to football, accelerations and decelerations are frequently completed actions by futsal players in order to stop and change direction (Illa, Fernandez, Reche, Carmona, & Tarragó, 2020; Ribeiro, Farzad, Illa, Ferraz, Nakamura, & Travassos, 2024). The absence of accelerations and decelerations is a limitation of the present study as it leaves gaps in our understanding of the high-intensity nature of futsal. Therefore, this could hinder futsal practitioners ability to fully understand the physical demands of futsal, restrict the development of effective training and injury prevention strategies (Harper, Carling, & Kiely, 2019).

The flat soled shoes worn by the research participants caused the silicone straps that housed the FIMUs to slide and move during locomotor and technical actions in futsal match-play. This is a limitation as IMUs must be fixated on the anatomical location of the wearer or it could have impacted the technical parameters of the FIMUs (Sheerin, Reid, & Besier, 2019). Therefore, the technical futsal variables quantified by the FIMUs could have been negatively affected by the silicone straps moving and sliding on the shoes of the research participants as the FIMUs quantify the technical performance variables in the medial-lateral plane (inside and outside of the foot).

Figure 3. showing the FIMU strap sliding up the ankle of one of the participant's during futsal match-play.

The inter-unit reliability and concurrent validity of the FIMUs was not established prior to the quantification of the technical performance variables in futsal. Without establishing inter-unit reliability and concurrent validity prior to the present study, it was not clear how accurate the level of agreement between the FIMUs, and video analysis would be when analysing the technical futsal variables. Whereas previous PlayerMaker™ research established inter-unit reliability and concurrent validity prior to the quantification of the technical performance variables in football training to ensure the accuracy and consistency of the data produced in their study (Marris, Barrett, Abt & Towlson, 2021).

6.2 Practical Applications

An LPS and FIMUs can quantify time-motion analysis variables indoors. Therefore, the findings from the present study can inform sports practitioners and organisations on the most viable option when choosing the technology to quantify velocity and distance measures. There were minimal differences within the mean distance covered and maximum velocity data in the present study. However, previous research has shown that the FIMUs underestimates maximum velocity at velocities above 6.26 m/s (Myhill, Weaving, Robinson, Barrett, & Emmonds, 2023) and the LPS overestimates maximum velocities the higher the velocity (Luteberget, Spencer, & Gilgien, 2018). However, the match-to-match variability of the time-motion analysis data can be utilised by sporting practitioners to identify the differences in physical performance in futsal match-play multiple matches.

Unless the FIMUs are fixated to the footwear of the futsal players, it is recommended that they are not utilised to quantify the technical load of futsal. Despite the long process of video analysis coding, the lack of agreement between video analysis and the FIMUs emphasises that video analysis coding is the most viable option for analysing the technical performance variables in futsal match-play scenarios. Although there is yet to be any research conducted on the technical variables of amateur futsal, the utilisation of the FIMUs in futsal is justified due to the technical abilities of professional futsal players being even greater at the elite level (Spyrou, Freitas, Marín-Cascales, Herrero-Carrasco, & Alcaraz, 2021). Therefore, the data quantified by the FIMUs during futsal match-play could be analysed by futsal coaches and scouts to identify the best technical futsal players. In addition, the technical FIMU data quantified in futsal match-play would be viable for footballing practitioners as futsal could serve as a different pathway into football rather than the traditional academy and transfer market systems (Travassos, Araújo, & Davids, 2018).

6.3 Future Research

Previous research facilitated between-unit reliability by fixating another FIMU on top of the initial FIMU (Myhill, Weaving, Robinson, Barrett, & Emmonds, 2023). A between-unit reliability analysis would be important for future research to identify any discrepancies between the two FIMU data sets. Therefore, placing multiple FIMUs on top of each other during sporting match-play would allow researchers to analyse the between-unit reliability of the time-motion analysis and technical performance variables quantified by the FIMUs.

Future researchers would be able to compare the time-motion analysis data quantified by the FIMUs and LPS in locomotor activities rather than the sporting match-play. Although this has been conducted previously in PlayerMaker™ FIMU research, the FIMU time-motion analysis data was not compared against an LPS (Myhill, Weaving, Robinson, Barrett, & Emmonds, 2023). Establishing the concurrent validity of the FIMUs and an LPS's time-motion analysis data in locomotor activities could be compared the results of the present study. The concurrent validity of the FIMUs and LPS's time-motion analysis in locomotor activities would also not be affected by the impact of a ball being kicked or physical contact with the FIMUs on the other research participant's footwear (Rossi, Pappalardo, Cintia, Iaia, Fernández, & Medina, 2018).

Future researchers could also analyse the concurrent validity of the technical performance variables quantified by the FIMUs in futsal-based activities outside of match-play. This could be completed similarly to previous PlayerMaker™ research, where the researchers could conduct a concurrent validity and inter-unit reliability analysis using video analysis software in activities outside of match-play scenarios (Marris, Barrett, Abt & Towlson, 2021). This future research results would not be affected by the foot-to-foot contacts of the research participants or the FIMUs lack of fixation on the footwear of the wearers, which may have led to false positives in the FIMU technical performance variables (Rossi, Pappalardo, Cintia, Iaia, Fernández, & Medina, 2018). Therefore, future research could aim to fixate the FIMUs on flat soled shoes or PlayerMaker™ could integrate their sensors into flat soled shoes to identify whether there are any differences in the technical load data measured in futsal match-play. This could also prevent the futsal players from removing the FIMUs from their footwear throughout futsal match-play as they would not slide or move on their footwear whilst they are playing.

7.0 References

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8.0 Chapter 8: Appendices

8.1 Appendix A

Informed Consent Form (Example)

Version number and date: Version One- 21/12/2022

CONSENT FORM

Title of study: The validation of a new foot-mounted inertial movement sensor units: A comparison between PlayerMaker™ and Catapult ClearSky™

Name of Researcher: William Witter

Please initial box

1. I confirm that I have read the information sheet dated Wednesday 14th December 2022, version one for the above study. I have had the opportunity to consider the information, ask questions and have had any questions answered satisfactorily. JS

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my legal rights being affected. I understand that once I have completed and submitted my questionnaires I cannot withdraw my anonymised data. I understand that the data I have provided up to the point of withdrawal will be retained. JS

3. I understand that research interviews will be audio recorded and that my anonymised verbatim quotes may be used in research reports and conference presentations. JS

4. I understand that relevant sections of my data collected during the study, may be accessed by individuals from the immediate research team, where it is relevant to my taking part in this research. I give permission for these individuals to have access to my records. JS

5. I understand that the research data, which will be anonymised (not linked to me), will be retained by the researchers and may be shared with others and publicly disseminated to support other research in the future. JS

6. I understand that my personal data will be kept securely in accordance with data protection guidelines, and will only be available to the immediate research team. JS

7. I give permission for the collection and use of my data to answer the research question in this study. JS

8. I agree to take part in the above study. JS

<u>John Smith</u>	<u>21.12.2022</u>	<u>J.SMITH</u>
Name of Participant	Date	Signature
<u>William Witter</u>	<u>21.12.2022</u>	
Name of Person taking consent	Date	Signature

8.2 Appendix B

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PRIVATE AND CONFIDENTIAL
Mr William Witter
Faculty of Health Sciences
University of Hull
Via email

Wednesday 3rd April 2024

RE: The validation of a new foot-mounted inertial movement sensor units: A comparison between Playermaker and Catapult ClearSky

Dear William,

I have reviewed your application and, having received advice from Research Governance, can confirm that we will provide retrospective ethical approval for your project following incorrect submission and subsequent advice from the Faculty of Business, Law and Politics.

The approval is valid until 30th June 2024. If you require an extension to this end date or in the event that any amendments are required to your study, please email FHS-ethicssubmissions@hull.ac.uk and the relevant paperwork will be provided.

Should an Adverse Event need to be reported, please complete the Adverse Event Form and send it to the Research Ethics Committee FHS-ethicssubmissions@hull.ac.uk within 15 days of the Chief Investigator becoming aware of the event.

I wish you every success with your study.

Yours sincerely

Dr Maureen Twiddy
Chair, FHS Research Ethics Committee

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Principle Investigator Name: William Witter   Principle Investigator Contact Number: 07932068931

Masters Research Project Participant Information Sheet

Project Title: The validation of a new foot-mounted inertial movement sensor units: A comparison between Playermaker™ and Catapult ClearSky™

Project data collection time period: January 2023-March 2024

Project Question: How does the concurrent validity and intra-unit reliability of Playermaker™ compare with Catapult ClearSky™ in Futsal?

Project Aims:

- ESTABLISH THE LEVEL OF AGREEMENT BETWEEN PLAYERMAKER™ AND CATAPULT CLEARSKY™
- COMPARE THE LEVEL OF AGREEMENT BETWEEN PLAYERMAKER™ AND CATAPULT CLEARSKY™ IN OPEN ENVIRONMENT AGAINST A CLOSED ENVIRONMENT.
- DETERMINE THE LEVEL OF AGREEMENT BETWEEN PLAYERMAKER'S TECHNICAL SOCCER/ FUTSAL ACTIONS AND VIDEO ANALYSIS CODING.
- ACCESS THE UNDERSTANDING OF THE PLAYERMAKER™ AND CATAPULT CLEARSKY™ TECHNICAL AND PHYSICAL SPORTS PERFORMANCE TRACKING METRICS THROUGHOUT THE PROJECT.

Tasks of the project participants:

- Consistently attend the Tuesday staff futsal session throughout the data collection project time period.

- Wear both the Catapult ClearSky™ vest and device and the Playermaker™ device concurrently for the entirety of every futsal session they attend and play in (open environment)

- Play on the same team with same participants as much as possible throughout the project to allow the Playermaker devices to best track the performance data of the participants.

- Play games of futsal during the session which are minimum of 10 minutes long to allow for the performance data to be tracked as accurately as possible.

- Allow all the futsal sessions to be video recorded for the principle investigator to complete video analysis coding.

- If permitted by Hull Sport, play every futsal session on the middle court of the University of Hull's sports centre to allow for optimal video recording of the entire session.

- Participants will be asked to complete a variety of movement tasks multiple times whilst wearing both the Playermaker™ and ClearSky™ devices (closed environment) throughout the period of data collection when they're available to do. These tasks include a 30 metre sprint, 6 minute walk, 5-0-5 Agility Test, Yo-Yo Intermittent Recovery and 30-15 Test. Each time before a task, the participants will complete the same warm up.

- Individually participate in surveys (and potentially interviews) before, during and at the end of the project to access the participants knowledge of the technology and data they have and want to receive from the research project.

8.3 Appendix C

Time-Motion Analysis Operation Definitions	
Total Distance	A numerical description of how far an individual/ athlete has travelled throughout an activity.
Relative Distance	The total distance covered by an individual/ athlete divided by the duration of their activity.
Maximum Velocity	The fastest the individual/ athlete has moved throughout an activity.
Velocity Zone 1 Distance	The total distance covered up by an individual/ athlete up to 1.5m/s
Velocity Zone 2 Distance	The total distance covered up by an individual/ athlete between 1.5 – 3m/s
Velocity Zone 3 Distance	The total distance covered up by an individual/ athlete between 3 – 4 m/s
High-Speed Distance	The total distance covered up by an individual/ athlete between 4 – 5 m/s
Sprinting Distance	The total distance covered up by an individual/ athlete greater than 5m/s
Sprints	The number of times an individual/ athlete achieved a speed equal or greater than 5m/s for equal or greater than 0.6 seconds.

8.4 Appendix D

PlayerMaker™ (2023) Technical Data Outputs Operation Definitions	
Ball Touches	The total number of times a wearer's leg came in contact with the ball.
Ball Releases	The total number of passes / kicks / shots.
Ball Possessions	The total number of times a wearer had control of the ball: - Pass, kick, or shot - Had 3 or more touches - Covered at least 6 meters with the ball
One Touch Possession	A single action in which the wearer receives and releases the ball.
Short Possession	A ball possession lasting 1.5 seconds or less.
Long Possession	A ball possession lasting more than 1.5 seconds.
Touch by Leg	Percentage of ball touches per leg
Release by Leg	Percentage of ball releases per leg
Receive by Leg	Percentage of balls received per leg
Kicking Velocity	The maximum speed of your foot per kick

8.5 Appendix E

Figure 1. Bland-Altman Plots showing the relationship between the PlayerMaker™ FIMUs and Video Analysis for Ball Releases throughout 10-minute games of recreational futsal match-play.

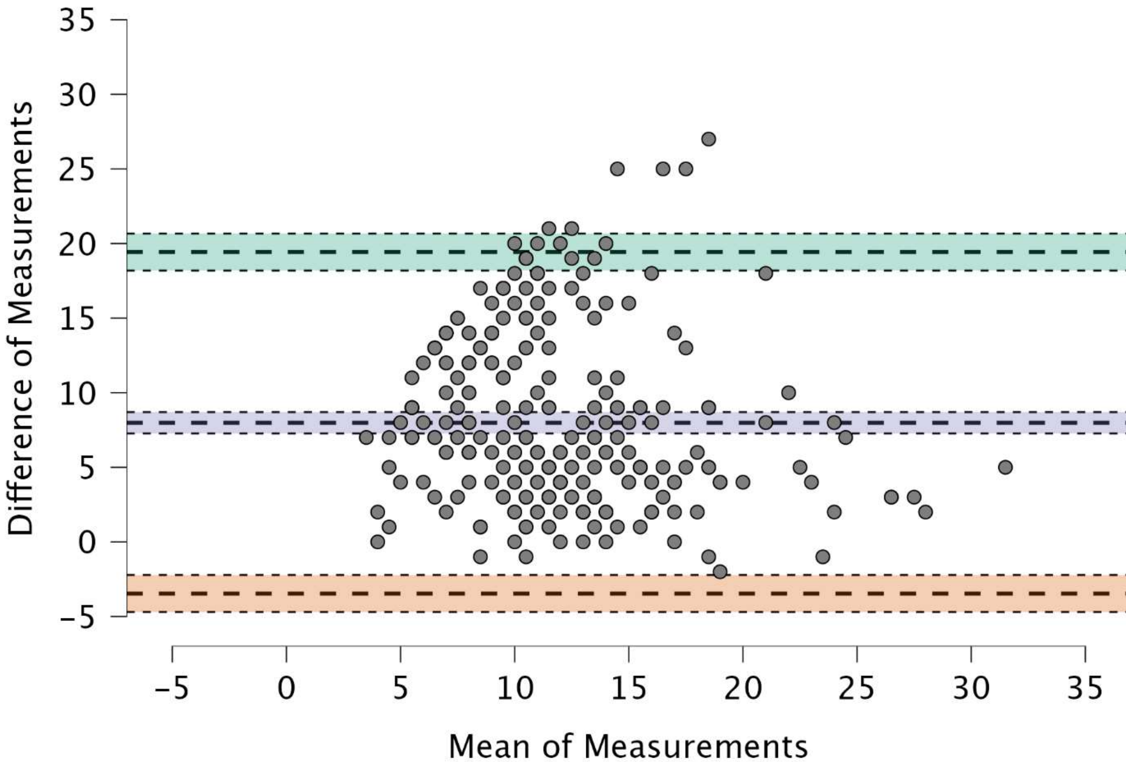

Table 1. showing the relationship between the PlayerMaker™ FIMUs and Video Analysis for Ball Releases.			
Bias & Limits	**Point Value**	**Lower 95% CI**	**Upper 95% CI**
Mean Difference + 1.96 SD	19.430	18.193	20.688
Mean Difference	7.985	7.270	8.699
Mean Difference - 1.96 SD	-3.461	-4.699	-2.223

8.6 Appendix F

Figure 2. Bland-Altman Plots showing the relationship between the PlayerMaker™ FIMUs and Video Analysis for Ball Touches throughout 10-minute games of recreational futsal match-play.

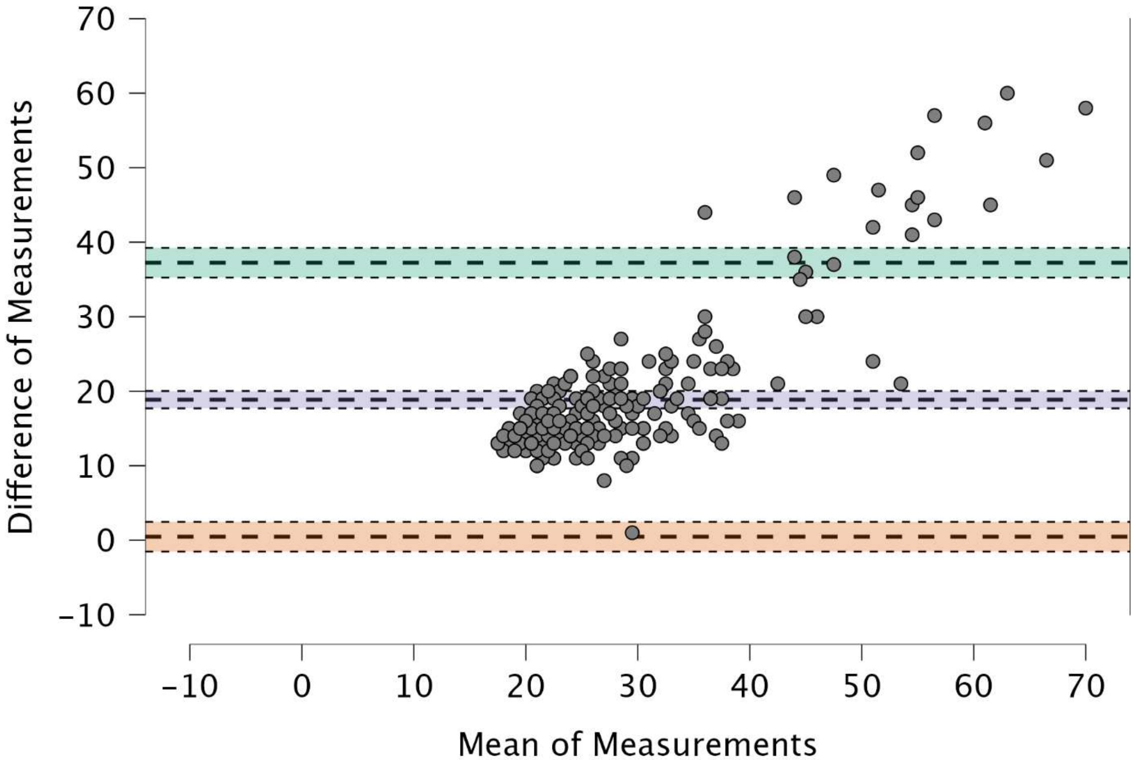

Table 2. showing the relationship between the PlayerMaker™ FIMUs and Video Analysis for Ball Touches throughout 10-minute games of recreational futsal match-play.

Bias & Limits	Point Value	Lower 95% CI	Upper 95% CI
Mean Difference + 1.96 SD	37.250	35.262	39.239
Mean Difference	18.861	17.713	20.009
Mean Difference - 1.96 SD	0.472	-1.517	2.460