International Journal of Kinesiology & Sports Science
ISSN: 2202-946X
www.ijkss.aiac.org.au

Peak Speed in Gaelic Games: A Systematic Review of GPS Methods

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ARTICLE INFO

Article history
Received: August 12, 2023
Accepted: October 22, 2023
Published: October 31, 2023
Volume: 11 Issue: 4

Conflicts of interest: None.
Funding: None

ABSTRACT

Background: Peak speed is an essential physical quality in Gaelic games due to the offensive, defensive, and transitional nature of the sports. **Objectives:** The aims of the study were to systematically search the literature for studies examining peak speed during Gaelic games match-play using Global Positioning System (GPS) technology, to assess the GPS methodologies implemented and report normative values for peak speed by sport. **Methods:** Keywords were combined to search and identify studies reporting peak speed values recorded using GPS technology during Gaelic games match-play. Key details such as GPS brand/model, number of satellites connected, and firmware version were extracted. A risk of bias tool was designed to rate the level of detection bias within each study. **Results:** Twenty-one (N=21) studies met the inclusion criteria. Eight studies examined peak speed in hurling and men's Gaelic football, respectively, while four camogie and one ladies Gaelic football study were identified. Twenty-nine percent (29%) of included studies were graded as having a high risk of bias in at least one category. Peak speeds between 7.81 to 9.97 $m \cdot s^{-1}$ were reported in hurling and men's Gaelic football and between 5.88 to 7.45 $m \cdot s^{-1}$ in camogie and ladies' Gaelic football. **Conclusions:** The dearth of literature examining peak speed in both female sports requires additional investigation, particularly in relation to the sprint profile of ladies Gaelic football. It is recommended that practitioners are cognisant of the methodological considerations which can be used as a 'checklist' to ensure accurate and reliable data are collected when using GPS technology to monitor peak speed.

Key words: Gaelic Football, Hurling, Camogie, Ladies Gaelic Football, Player Monitoring, Maximum Velocity, GNSS, Maximum Sprinting Speed

INTRODUCTION

Gaelic games are indigenous Irish games promoted and governed under the following amateur and cultural organisations; the Ladies Gaelic Football Association, the Camogie Association, and the Gaelic Athletic Association (Men's football and hurling). Traditionally, Gaelic games refers to women's and men's Gaelic football, camogie, hurling, rounders, and handball. For the purpose of the current review, 'Gaelic games' will refer to women's and men's Gaelic football, camogie, and hurling. Women's Gaelic football is officially called 'Ladies Gaelic football' and will be referred to as 'Ladies Gaelic football' in the current review. All four sports are played between two teams of fifteen players respectively. Games are typically played on a rectangular grass pitch 140 m long and 90 m wide with H-shaped goalposts positioned at both ends. Ladies and men's Gaelic football use a leather football similar in size to the ball utilised in soccer and can be played by hand or foot (Cullen et al., 2013). Camogie and hurling are the female and male versions of the same stick and ball game, although subtle rule differences exist (Young et al., 2019a; Young et al., 2021). All games aim to outscore the opposition, achieved by striking the ball over the crossbar and between uprights (1 point) or under the crossbar and into the net (3 points). Games consist of two teams of fifteen players (one goalkeeper and fourteen outfield players). Traditionally, formations consist of three players in the full back-, half back-, half forward- and full forward lines, respectively, with the remaining two outfield players in midfield (Collins et al., 2018). All players represent their club (sub-elite) team while those deemed most talented are selected to additionally represent their inter-county (elite) team, at their respective age grade (Young et al., 2021). Underage and women's games are comprised of two thirty-minute halves, while senior inter-county hurling

Published by Australian International Academic Centre PTY.LTD.

http://dx.doi.org/10.7575/aiac.ijkss.v.11n.4p.25

and men's Gaelic football consist of two thirty-five-minute halves.

Maximum sprinting speed is the fastest speed a player can attain while sprinting. However, players may not always achieve 'true' maximum sprinting speed during match-play (Malone et al., 2023). Malone et al., (2023) reported that players, across all positions, achieved 86 ± 4% of maximal sprinting speed during match-play in elite ladies Gaelic football. The term 'peak speed' has been used within the Gaelic games literature to describe the maximum sprinting speed achieved during match-play (Collins et al., 2018; Gamble et al., 2019). Offensively, peak speed aids in the creation of scoring opportunities as it allows players to evade opponents, solo the ball into space and create sufficient separation from a defender to shoot (Duggan et al., 2020). Defensively, peak speed supports players in their pursuit of opposition players to prevent scoring opportunities, win a contest for possession, and assist in the swift transition from defence to attack and vice versa (Young et al., 2019a). The recent publication of the 'Gaelic Games Player Pathway and Sport Science 2030 Vision' also highlights the need for athletic development sessions to focus on speed development from 12+ years of age to adult level (Gaelic Games Association, Ladies Gaelic Football Association, & Camogie Association, 2023). An in-depth review of peak speed during Gaelic games match-play has yet to be conducted. Research examining this literature on peak speed can additionally identify gaps and help inform where future research is needed which' with this will ultimately contribute to a more comprehensive understanding of the role peak speed plays in Gaelic games.

Within the sport science and Gaelic games literature Global Positioning System (GPS) technology has become popularised over the last 10 years (Malone et al., 2017; Whitehead et al., 2018). GPS technology are devices used to quantify players' locomotion and data collected are typically recorded as the distance covered or count of distinct efforts categorised into different 'speed zones' (Varley, Jaspers, Helsen, & Malone, 2017). For example, distance- and distance- and velocity- derived outputs such as 'high-speed running', 'very-high speed running', 'sprinting', and peak speed are commonly reported (Mooney et al., 2021; Whitehead et al., 2018; Young et al., 2019a). Monitoring external parameters such as these allow practitioners to periodise, evaluate, and subsequently prescribe an appropriate external training load to players (Aughey, 2011; Malone et al., 2017; Varley et al., 2017). Thus, GPS monitoring helps reduce spikes in training load and facilitates optimal preparation of players for the demands of competition (Beato, Coratella, Stiff, & Iacono, 2018). However, there are a number of technological and practical limitations to consider when interpreting data collected via GPS technology (Beato et al., 2018).

Numerous studies have highlighted the influence of methodological variables on data collected using GPS technology. Examples include; sampling frequency (Scott, Scott, & Kelly, 2016), brand/model (Thornton, Nelson, Delaney, Serpiello, & Duthie, 2019), firmware version (Malone et al., 2017), data processing technique (Thornton et al., 2019), and minimal effort of duration (MED) (Varley et al., 2017). Considering these factors, recent publications have highlighted the 'risk of bias' data collected and reported using GPS technology is subject to (Harper, Carling, & Kiely, 2019). This makes comparison of outputs reported between-studies difficult. A review of the methods employed while using GPS technology to assess peak speed in Gaelic games has yet to be conducted.

Normative values provide mean and standard deviation performance outcomes collected during the monitoring of athletes i.e., strength, power, speed. These data allow practitioners and researchers to compare between similar athletic cohorts. Peak speed data collected via GPS technology and monitored throughout the season can be compared against normative data published in the literature. Comparison can help inform an athletes upcoming training priorities by identifying an athlete's limitations which can subsequently be targeted in training (McMahon, Turner, & Comfort, 2018). Additionally, normative positional values can be used as a method of talent identification particularly if certain positions require greater development of specific physical qualities. In Gaelic games a collation of normative peak speed values has yet to be reported.

The aims of this systematic review were to (1) conduct a systematic search of the scientific literature and identify peak speed recorded during match-play using GPS technology in the four Gaelic games; (2) report the methodological variables employed when using GPS technology to monitor peak speed; and (3) provide normative values for peak speed.

METHODS

Literature Search

A systematic search of the literature was conducted following the PRISMA 2020 guidelines (Page et al., 2021). Systematic searches were undertaken in electronic databases CINAHL Complete, PubMed, Scopus, SPORTDiscus, and Web of Science from inception to 15th September 2022. Keywords for each search term (sporting population and peak speed) were developed and selected through pilot searching of known studies (titles, abstracts, keywords, and full-texts). Keywords were combined using the operators 'OR' and 'AND' to form the final search phrase (Table 1). The search field selected in all databases was either "all fields" or "all text". All record types (journal articles, books, conference papers etc.,) were permitted. Additional studies were identified from the reference lists of included studies, searched, and imported from Google Scholar.

Study Selection

Reference management software (Zotero, 6.0.4, USA) was used to import studies from each database. Duplicate studies were identified and removed. Studies were screened over two phases independently by two authors (EMcG and RH). First, non-relevant studies were removed based on title and abstract, followed by removal after a full-text review if the inclusion criteria were not met (Table 2). Disagreement over study selection was resolved by a third author (KB).

Data Extraction and Synthesis

One author (EMcG) extracted relevant data from included studies on to an appropriately designed Microsoft Excel (Microsoft, 16.60, Redmond, WA, USA) spreadsheet. Studies included were categorised by sport and subsequently

Table 1. Keywords and search terms used in each database

Search Term	Keyword
Sporting Population	“Women’s Gaelic football” OR "Ladies Gaelic football" OR “Men’s Gaelic football” OR “Gaelic football" OR "Gaelic games" OR hurling OR hurlers OR camogie NOT soccer
Peak Speed	"top speed” OR “maximal speed” OR “maximal velocity” OR “peak velocity” OR “peak speed” OR “Global Positioning System” OR “GPS technology” OR “Global Positioning System” OR “Global Navigation Satellite System” OR GNSS OR “match demands" OR "game demands" OR "match play" OR “match play demands” OR "running performance" OR sprint* OR "activity profil*" OR "work rate" OR "activity pattern" OR “sprint performance” OR “speed performance” OR “sprint tim*” OR “sprint velocity” OR acceleration OR deceleration
Search Phrases:	1 AND 2

Table 2. Criterion based on title/abstract and full-text screening

Criterion	Inclusion criteria
1	Any record type (journal articles, books, conference papers etc.,) that examined peak speed during match-play
	OR training intervention studies that monitored peak speed during match-play
2	Study participants were required to be ladies or men’s Gaelic football, camogie or hurling athletes
3	Study participants were required to have a mean age ≥ 16 years old
4	Studies must be available in English
	Exclusion criteria
1	Studies utilising a similar data set from a past publication (salami slicing)
2	Studies or authors that did not provide results for peak speed purportedly assessed

by author surname (A-Z) in the spreadsheet. Study information (author, year, title, study design, playing standard, time of year, seasons (n), participants (n), games (n), teams (n), data files (n)), athlete characteristics (age, body mass, height, position), timing technology (brand, model, sampling frequency), data collection (satellites (n), horizontal dilution of precision (HDOP) (n), firmware version), data processing (minimal effort of duration (MED), raw data or software processed), normative profile (matches played (n), if position specific data was reported); and normative performance values (descriptive statistics) for peak speed were extracted from included studies. When reported as $km \cdot h^{-1}$ in the included studies, descriptive statistics (mean ± SD) were divided by 3.6 to calculate $m \cdot s^{-1}$, as meters per second is the SI unit for speed.

Although alternatively referred to as ‘top speed’, ‘maximal velocity’, or ‘peak velocity’, in the literature, the current review uses the terminology ‘peak speed’ to describe the highest speed/velocity achieved by an athlete during match-play.

Missing Data

If mean values claimed to be collected in studies meeting the inclusion criteria were not reported, these data were requested from the corresponding authors via email. However, not all desired data were obtained, and three studies were excluded.

Risk of Bias Assessment

The PRISMA guidelines advocate using a component based approach that is domain specific i.e., Cochrane risk of bias tool (Higgins, Green, & Cochrane Collaboration, 2008; Liberati et al., 2009; Page et al., 2021). Two recent publications have illustrated the influence of various methodological factors associated with GPS use in quantifying peak speed (Malone et al., 2017; Varley et al., 2017). The type of bias most applicable to GPS technology is detection bias (Harper et al., 2019). Detection bias relates to the systematic differences in how outcomes are determined between studies. Peak speed values obtained are subject to detection bias when using different GPS devices and the variations inherent within- and between- devices (see results and discussion section for further detail). Examples include; HDOP (describe the strength of the satellite configuration and its effect on the accuracy of collected data), the number of satellites interacting with GPS device (representative of signal quality) and MED (demarcates the minimal time required for a speed to be above a pre-determined threshold in order to identify it as a certain movement effort).

A checklist for reporting GPS methodological variables for relevant included studies and assessing risk of bias was created under three main categories (‘data collection, ‘data processing’, ‘normative profile’) (Harper et al., 2019), based on recent GPS reporting recommendations (Malone et al., 2017; Varley et al., 2017). Checklists were independently assessed by two authors (EMcG, RH) using one of six responses; (1) ‘yes’, (2) ‘no’, (3) ‘no information’, (4) ‘not applicable’, (5) ‘probably yes’ and (6) ‘probably no’ (Higgins et al., 2008). A verdict on risk of bias was submitted by the two authors for all three categories based on the checklist. Three outcomes were possible: (1) low RoB: plausible bias unlikely to substantially vary the results; (2) unclear RoB: plausible bias that prompts some uncertainties about the results; and (3) high RoB: plausible bias that substantially reduces confidence in the results (Higgins et al., 2008). The inter-rater agreement (kappa) for the ‘data collection, ‘data processing’, and ‘normative profile’ were 0.85, 0.70, and 0.65 respectively, which are considered good to excellent levels of agreement (Higgins et al., 2008). A final verdict was reached by consensus discussion between authors.

RESULTS

Search Results

In total, the search strategy returned one-thousand and seventy-one (n = 1071) records. Records were first screened by

title and abstract; duplicates were removed (n = 244) followed by non-relevant records (n = 787). Prior to the full-text review forty (n= 40) records remained. A further nineteen (n = 19) were removed, resulting in twenty-one (n= 21) records which met the inclusion criteria. Two records were subsequently removed as the desired peak speed results were absent from the research papers and were not provided by the authors upon request (n = 19). Two additional records (n = 2) identified from the reference lists of included records and met the inclusion criteria were added. In total, twenty-one records (n = 21) were included (Figure 1).

Study Characteristics

Study characteristics and descriptive statistics (mean ± SD) of the twenty-one included studies are reported in Table 3. One study assessed peak speed in ladies Gaelic football, four in camogie, eight in hurling and eight in men's Gaelic football.

GPS Technologies used to Monitor Peak Speed and Risk of Bias

The GPS technologies used to record peak speed during match-play are reported in Table 4. Seventeen (81%) studies employed GPS units with a sampling frequency equal to or greater than 10 Hz. The average number of satellites the GPS were linked to during data collection, a measure of signal quality, and the HDOP number were stated in four (19%) studies. The risk of bias rating (low, unclear, or high) for each category (data collection, data processing and normative profile) is shown in Table 4.

Risk of Bias

A percentage breakdown of the overall RoB grading (low, unclear, or high) for each category (data collection, data processing and normative profile) is illustrated in Figure 2. The greatest high RoB was detected in the data collection category (29% high RoB). Data processing had the greatest percentage of uncertainty (71% unclear RoB). The lowest RoB was found in the data collection category (57% low RoB); 13 (62%) studies reported the firmware version of the GPS device used.

Normative Values for Peak Speed

Descriptive statistics (mean ± SD) for peak speed reported in $m \cdot s^{-1}$ are given in Figure 3. Positional values are reported where data are available.

DISCUSSION

The current review is the first to examine peak speed monitored during match-play within the Gaelic games literature. The second aim of the review was to examine methodologies employed to assess peak speed during match-play using GPS technology. Interestingly, in addition to the large variation in the methods used to assess peak speed, numerous studies failed to report key methodological information, thus making comparison between studies difficult. Presenting normative values for peak speed was the final aim of the review. However, normative values are contingent upon the robustness of the methods employed, thus the values presented in the current review should be interpreted with caution.

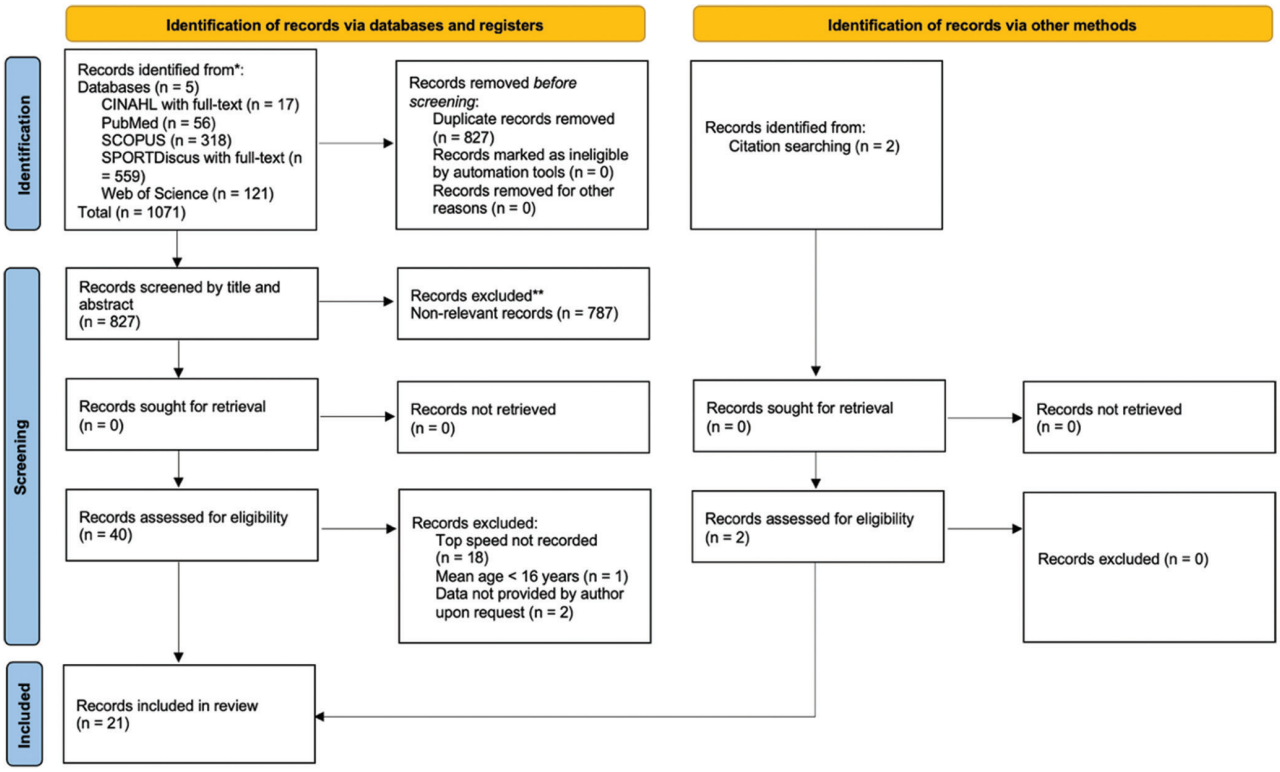

Figure 1. PRISMA 2020 Search Strategy Flow

Table 3. Included study characteristics

Author	Playing standard	Time of season/year	Sample			
			n	Age (years)	Body mass (kg)	Height (m)
		Ladies Gaelic football				
Malone et al., (2023)	Senior Inter-county	In-season (League, Challenge games, Championship Jan 2021-Mar 2022)	33	24 ± 5	63.0 ± 4.0	1.70 ± 0.05
		Camogie				
Connors et al., (2022a)	Senior Inter-county	In-season (Championship)	31	24 ± 4	67.0 ± 7.5	1.67 ± 0.06
Connors et al., (2022b)	Senior Inter-county	In-season (League & Championship)	33	25 ± 3	64.4 ± 3.9	1.86 ± 0.07
O'Grady et al., 2022)	Senior Inter-county	In-season (League & Championship; Feb-Sep 2018-2020)	43	23 ± 5	68.0 ± 9.0	1.74 ± 0.05
Young et al., (2021)	Senior Inter-county	In-Season (Feb-Sept 2017-2019)	36	23 ± 4	65.0 ± 6.0	1.68 ± 0.05
		Hurling				
Collins et al., (2018)	Senior Inter-county	In-season (League & Championship)	94	26 ± 4	NR	NR
Egan et al., (2021)	Senior Inter-county	In-season (League 2017-2020) In-season (Championship 2017-2020)	50	27 ± 5	87.3 ± 6.2	1.82 ± 0.06
Young et al., (2020a)	Senior Inter-county	In-season (Feb-Sept 2016-2018)	48	27 ± 5	88.0 ± 5.0	1.81 ± 0.06
Young et al., (2020b)	U17 Inter-county	In-season (May-Sept 2017-2018)	76	17 ± 0	69.4 ± 6.1	1.77 ± 0.06
Young et al., (2019a)	Senior Inter-county	In-season (League & Championship 2017-2018)	51	28 ± 4	88.0 ± 5.0	1.84 ± 0.06
Young et al., (2019b)	Senior Inter-county	In-season (Feb-Aug 2016-2018)	36	27 ± 4	86.0 ± 4.0	1.81 ± 0.06
Young et al., (2018a)	Senior Inter-county & Senior Club	In-season (League) In-season (Club League)	24 24	26 ± 4	85.1 ± 5.3	1.82 ± 0.06
Young et al., (2018b)	U21 Inter-county	In-season (2017)	95	21 ± 1	77.4 ± 2.9	1.81 ± 0.06
		Men's Gaelic football				
Boyle et al., (2020)	Senior Inter-county*	In-season (2017-2018)	52	25 ± 4	85.6 ± 6.3	1.82 ± 0.06
Cullen et al., (2020)	Senior Inter-county	In-season (Jan-Sept 2017)	37	26 ± 4	86.0 ± 4.0	1.81 ± 0.15
Daly et al., (2020)	Senior Club	In-season	41	23 ± 4	80.6 ± 9.5	1.78 ± 0.08
Gamble et al., (2019)	Senior Inter-county	Pre-season	36	24 ± 3	NR	NR
Malone et al., (2017)	Senior Inter-county	In-season (Feb-Sept 2010-2013)	50	26 ± 4	79.0 ± 7.0	1.83 ± 0.07
Malone et al., (2016)	Senior Inter-county	In-season (Feb-Sept 2014-2015)	50	24 ± 6	81.0 ± 7.0	1.80 ± 0.07
Mangan et al., (2020)	Senior Club (Div 1) Intermediate Club (Div 1)	In-season (Feb-Sept 2018) In-season (Feb-Sept 2018)	37 31	24 ± 4 24 ± 5	84.0 ± 7.9 80.0 ± 1.1	1.83 ± 0.06 1.80 ± 0.05
Mooney et al., (2021)	U20 Inter-county	In-season (May-Aug 2018-2019)	29	20 ± 1	1.81 ± 5.6	80.7 ± 0.06

NR Not reported, * = Conference paper, Div = Division

Table 4. GPS technologies used to monitor peak speed

Author	Model (Brand)	Data Collection				Data Processing		Risk of Bias		
		SF (Hz)	SAT (n)	HDOP (n)	Firmware version	MED (s)	Raw/software	A	B	C
Ladies Gaelic football										
Malone et al., (2023)	PlayerTek (Catapult Sports)	10	NR	NR	J3.20	NR	Raw	L	U	L
Camogie										
Connors et al., (2022a)	PlayerTek (Catapult Sports)	10	NR	NR	NR	NR	PlayerTek Software	U	U	U
Connors et al., (2022b)	PlayerTek (Catapult Sports)	10	NR	NR	NR	NR	Raw	U	U	U
O'Grady et al., (2022)	Apex (STATSports)	10	NR	NR	2.5	≥ 1.0	STATSports, Apex 2.1.15.	L	H	L
Young et al., (2021)	Apex (STATSports)	10	NR	NR	2.0.2.4	NR	STATSports, Apex	L	U	L
Hurling										
Collins et al., (2018)	NR (VX Sport)	4	NR	NR	NR	NR	NR	H	U	U
Egan et al., (2021)	Apex (STATSports)	10	20 ± 2	1.4 ± 2	4.14 RCO	≥ 1.0	STATSports, Apex (4.14 RCO)	L	L	L
Young et al., (2020a)	Viper (STATSports)	10	19 ± 7	1 ± 1	2.7.1.83	NR	STATSports Viper 1.2	U	U	U
Young et al., (2020b)	Viper (STATSports	10	NR	NR	2.7.1.83	≥ 1.0	STATSports, Viper	U	L	U
Young et al., (2019a)	Viper (STATSports)	10	NR	NR	Viper 2.28	≥ 1.0	Raw	L	L	L
Young et al., (2019b)	Viper (STATSports)	10	NR	NR	Viper 2.28	NR	Raw	L	U	L
Young et al., (2018a)	SPI Pro (GPSports)	5	NR	NR	NR	NR	Team AS Software (SPI Elite, GPSports)	H	U	L
Young et al., (2018b)	Viper (STATSports)	10	19 ± 7	1 ± 1	Viper 2.28	NR	STATSports Viper 1.2	U	U	U
Men's Gaelic football										
Boyle et al., (2020)	NR (VX Sport)	10	NR	NR	NR	NR	NR	H	H	H
Cullen et al., (2020)	Viper (STATSports)	10	NR	NR	NR	NR	STATSports Viper 3.2	L	U	U
Daly et al., (2020)	Apex (STATSports)	18	NR	NR	NR	NR	NR	H	L	L
Gamble et al., (2019)	OptimEye S5 (Catapult Sports)	10	14.3 ±1.3	0.58 ± 0.05	v6.92	NR	Sprint (v5.1.7)	L	U	U
Malone et al., (2017)	Issue 330a (VX Sport)	4	NR	NR	4.01.1.0	NR	Raw	L	U	H
Malone et al., (2016)	Issue 330a (VX Sport)	4	NR	NR	3.26.7.0	NR	Raw	L	U	H
Mangan et al., (2020)	LT (GPEXE)	18	NR	NR	NR	NR	GPEXE Bridge	U	U	H
Mooney et al., (2021)	PlayerTek (Catapult Sports)	10	NR	NR	J3.18	NR	PlayerTek Team Application; V2.4.5	U	U	H

A Data Collection Rob, *B* Data Processing RoB, *C* Normative Profile RoB, GPS Global Positioning System, *HDOP* Horizontal dilution of precision, *MED* Minimal effort duration, *NR* Not reported, *s* second, *SAT* Satellites, *SF* Sampling frequency, (*L*) low risk of bias (plausible bias unlikely to substantially vary the results), (U) = unclear risk of bias (plausible bias that prompts some uncertainties about the results), (H) = high risk of bias (plausible bias that substantially reduces confidence in the results)

Disparity in Sports Examined

To achieve optimal performance, athletes require appropriate levels of physical preparation to meet the demands of their sport. Seventy-six percent (76%) of studies included in the review were conducted on the two male Gaelic games sports. The remaining 24% (n =5) of studies were conducted on camogie (n = 4) and ladies Gaelic football (n = 1) and have only recently been published (Connors et al., 2022a, 2022b; Malone et al., 2023; O'Grady et al., 2022; Young et al., 2021). Although there has been a recent increase of publications in camogie, which suggests an emerging trend in female Gaelic sports research; there is still a paucity in the literature in ladies Gaelic football. Without accurate information on female Gaelic games, coaches may consult research conducted on male athletes or other female team sports to inform their training practices. Future research should seek to investigate peak speed and elucidate the sprint profile of ladies Gaelic football match-play.

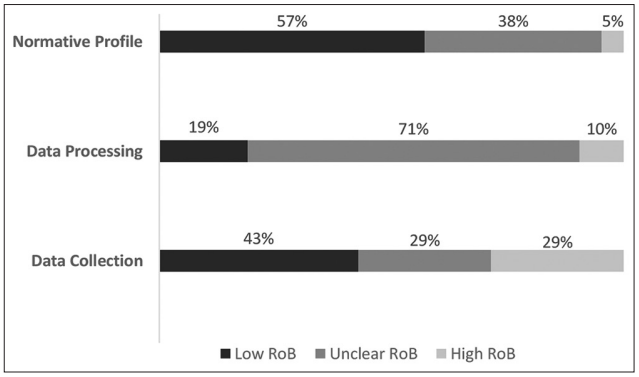

Figure 2. Risk of Bias Graph

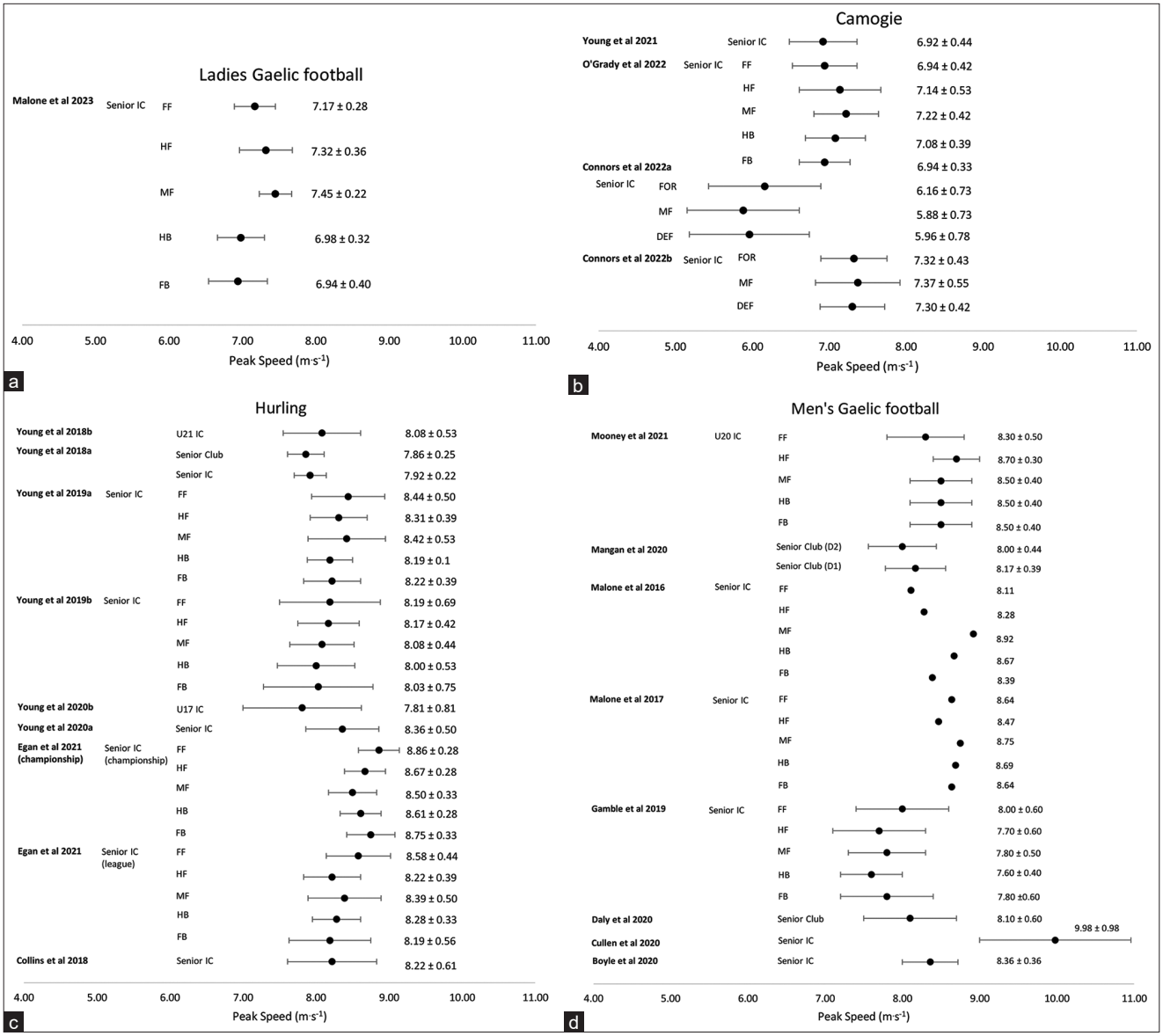

Figure 3. (a-d) Normative values (mean ± SD) for peak speed obtained via GPS technology
D1 Division 1, *D2* Division 2, DEF Defenders, *FOR* Forwards, *FB* Full-backs, *HB* Half-backs, *MF* Midfielders, *HF* Half-forwards, *FF* Full-forwards, *IC* Intercounty

GPS Technology Methodologies

Sampling frequency

GPS technology collects time and instantaneous velocity data and allows metrics derived from these to quantify an athlete's locomotive performance during training and competition (Varley et al., 2017). These data allows coaches and researchers to quantify competition demands and monitor training (Malone et al., 2017; Varley et al., 2017). Sampling frequency has been reported to be an important feature of GPS devices for accurately and reliably quantifying an athlete's locomotor profile (Scott et al., 2016). Eighty-one percent (81%) of included studies used GPS technology (Catapult Sports; n = 5, GPEXE; n = 1, STATSports; n = 10, VX Sport; n = 1) with a sampling frequency ≥ 10 Hz to collect data (Table 4). Peak speed recorded using devices with ≥ 10 Hz sampling frequency has been shown to have greater accuracy in comparison to devices using ≤ 5 Hz (Scott et al., 2016). Although not all GPS devices in the included studies have been independently examined, it is generally accepted that devices with a sampling frequency of < 10 Hz have a large degree of error when measuring peak speed (Aughey, 2011; Scott et al., 2016). Subsequently, all devices with a sampling frequency of < 10 Hz were rated as having a high RoB during data collection (Harper et al., 2019).

Signal quality

During data collection the signal quality received by GPS devices affects the accuracy of data recorded (Malone et al., 2017). Signal quality is evaluated based on the number of satellites communicating information with the GPS device. Equally, signal strength from satellites to each device must be sufficient (Malone et al., 2017). A minimum of four satellites is required although at least six has been recommended based on anecdotal observations (Malone et al., 2017). A moderate negative correlation (r = -0.50) exists between total distance error and the number of satellites interacting with the device (Beato et al., 2018; Gray, Jenkins, Andrews, Taaffe, & Glover, 2010; Scott et al., 2016). This may have implications for peak speed values reported although the influence has yet to be investigated. Only 19% of studies included reported the number of satellites obtained during data collection (Egan et al., 2021; Gamble et al., 2019; Young et al., 2020a; Young et al., 2018b). However, some GPS devices do not allow users to view the number of satellites connected to the devices or HDOP (Beato et al., 2018). Manufacturers should make this information available to users and enable the evaluation of the quality of data collected (Malone et al., 2017). Furthermore, only four (21%) studies stated HDOP information (Gamble et al., 2019; Young et al., 2020a; Young et al., 2018b). HDOP is a metric used to describe the strength of the satellite configuration and its effect on the accuracy of the data collected (European GNSS Agency, 2018). It refers to the geometrical 'spread' of satellites interacting with the GPS device (Isik et al., 2020; Malone et al., 2017). HDOP can be reported from 0-50 and can be rated as ideal (<1), excellent (1-2), good (2-5), moderate (5-10), fair (10-20) and poor (>20) (Isik et al., 2020; Malone et al., 2017). As previously recommended, researchers and coaches should check data quality by examining satellite and HDOP information and exclude data files that fall outside acceptable ranges (Malone et al., 2017). Additionally, both the number of satellites and HDOP information should be stated in future research utilising GPS technology.

Minimal effort of duration (MED)

MED is used to demarcate the minimal time required for a speed to be above a pre-determined threshold in order to identify movement efforts. For example, a constant speed needs to be maintained for over ≥ 0.5 seconds in order to be counted as a new peak speed. This consideration is useful as GPS speed data is often accompanied with noise or erroneous spikes; MED ensures only realistic efforts are included (Varley et al., 2017). Although several included studies stated the MED for acceleration or deceleration efforts, only four studies specifically stated sprint MED (≥1.0 s) (Egan et al., 2021; O'Grady et al., 2022; Young et al., 2019a; Young et al., 2020b). The influence of using different MEDs has shown that the number of sprint efforts declined exponentially as MED increased during soccer match-play (Varley et al., 2017). Furthermore, a change in MED of 0.1 second was shown to substantially influence the number of sprint efforts recorded (Varley et al., 2017). Whether MED can also influence peak speed values has yet to be examined. Currently, there is no consensus on the appropriate MED for sprint efforts or peak speed. However, coaches and researchers need to be cognisant and report the MED used in future to enable comparison between studies.

Software

Filtering algorithms are incorporated into every GPS device with the aim of reducing poor quality data. Proprietary software, which can automatically interpolate, smooth or extract, is a straightforward and efficient way of evaluating data collected during training or competition (Malone et al., 2017; Thornton et al., 2019). However, manufacturers provide little information regarding filters and algorithms used to process data. Alternatively, some users export and analyse raw data independently from proprietary software to further analyse desired metrics not provided by the manufacturers software (Thornton et al., 2019). Twelve studies stated the use of proprietary software (Connors et al., 2022a; Cullen et al., 2020; Egan et al., 2021; Gamble et al., 2019; Mangan et al., 2020; Mooney et al., 2021; O'Grady et al., 2022; Young et al., 2020a; Young et al., 2018b; Young et al., 2020b; Young et al., 2018a; Young et al., 2021), six processed raw data (Connor et al., 2022b; Malone et al., 2017; Malone et al., 2023, 2016; Young et al., 2019a; Young et al., 2019b), and three did not report the data filtering technique used (Boyle et al., 2020; Collins et al., 2018; Daly et al., 2020). Furthermore, although peak speed remained unchanged, research has shown that the number of acceleration (> 1.5 $m \cdot s^{-2}$) detected from the same data set collected via GPS technology decreased from 251 ± 65 to 177 ± 53 efforts when the processing software underwent an update (Buchheit et al., 2014).

Firmware

Firmware is a small piece of code embedded in a device's chipset written by the manufacturer. Raw data exported from proprietary software are often prefiltered by the device's firmware to reduce noise (Malone et al., 2017). Firmware version was reported in twelve (63%) included studies (Egan et al., 2021; Gamble et al., 2019; Malone et al., 2017; Malone et al., 2016; Mooney et al., 2021; O'Grady et al., 2022; Young et al., 2020a; Young et al., 2019a; Young et al., 2019b; Young et al., 2018b; Young et al., 2020b; Young et al., 2021). Similar to filtering software, firmware can undergo updates. Due to the potential influence software and firmware updates can have on data collected, it is recommended both software and firmware versions remain constant during longitudinal data collection. Additionally, both versions used should be reported.

Risk of Bias

Considering all variables reported or otherwise, our risk of bias (RoB) assessment graded each study by category (data collection, data processing, normative profile) (Figure 2). Considering the lack of reporting and methodological variation of the studies included in the review there was a high risk of detection bias in twenty-nine percent (29%) in at least one category (data collection, data processing, normative profile). In future, coaches and researchers should be cognisant of the outlined factors affecting peak speed data when using GPS technology. Therefore, it is important all factors are reported. This will aid comparison between studies, reduce the risk of detection bias, ultimately enhancing the methodological soundness of data reported.

Normative Values

An important factor to be aware of when examining the normative values is the time of season data collection took place. This is highlighted by the work of Egan et al. (2021) which examined peak speeds achieved during match-play throughout league and championship periods. All positions achieved significantly ($p < 0.001$) greater peak speeds in the championship in comparison to the league with a mean increase of 0.36 $m \cdot s^{-1}$. This may be due to the championship typically being played during the warmer months (May - September) which would tend to yield firmer pitches in comparison to the the softer pitches experienced during the league (January - April) (Egan et al., 2021). Additionally, by the time the championship competition commences, players have accumulated months of training. This likely results in players being in greater physical condition than they would be during the league period and thus are capable of achieving higher peak speeds. Traditionally and anecdotally, the championship is considered the most important competition which may result in players having heightened levels of motivation which also may contribute to the attainment of greater peak speeds. Peak speed values reported from the other studies in elite hurling were collated from both the league and championship (Collins et al., 2018; Young et al., 2020a; Young et al., 2019a; Young et al., 2019b). This might explain the lower team mean peak speed values in these studies as data from the league period may have resulted in lower peak speeds being achieved overall.

In hurling and camogie the ball can travel up to 60-80 m down field within one play, this likely reduces the necessity to sprint long distances. Mean sprint length has been reported to be 18.6 ± 3.1 m in senior inter-county hurling, ranging from 7 to 33 m (Young et al., 2019a) and 17 ± 4 m and 7 to 30 m in camogie (O'Grady et al., 2022). The range and mean length of sprint efforts in male senior inter-county football has yet to be reported. However, total sprint distance appears to be greater during Gaelic football match-play (445 ± 69 m; 477 ± 194 m) (Malone et al., 2017; Mooney et al., 2021) in comparison to hurling 350 ± 93 m (Young et al., 2019b). Thus, Gaelic football players may have a greater number of sprints as well as sprint over a great distance during match-play. Therefore, Gaelic football may provide a greater opportunity to reach 'true' peak speed during match-play in comparison to hurling.

One included study reported a team mean peak speed of 9.98 ± 0.98 $m \cdot s^{-1}$ during match-play (Cullen et al., 2020). This value is markedly greater than reported peak speeds in any other included study. For context, male National Rugby League (NRL) outside backs reported a mean peak speed of 9.30 ± 0.05 $m \cdot s^{-1}$ during a 40 m linear sprint test while recording peak speeds that were 12% slower during match-play (Gabbett, 2012). Furthermore, the fastest international male soccer players rarely approach 10.00 $m \cdot s^{-1}$ during 40 m linear sprint testing (Haugen, Breitschädel, & Seiler, 2019). Additionally, considering the standard deviation reported in combination with the mean, this would suggest that the sample included individuals with peak speeds in excess of 11.00 $m \cdot s^{-1}$. These speeds are comparable to those of elite male 100 m sprinters which seems unlikely (Healy, Kenny, & Harrison, 2019).

The mean peak speed recorded over 22 and 20 games in inter-county camogie outfield players was 6.92 ± 1.6 $m \cdot s^{-1}$ and 7.05 ± 0.42 $m \cdot s^{-1}$ respectively (O'Grady et al., 2022; Young et al., 2021). One study reported a mean peak speed of 7.30 ± 0.43 $m \cdot s^{-1}$, 7.37 ± 0.55 $m \cdot s^{-1}$, and 7.32 ± 0.43 $m \cdot s^{-1}$ for defenders, midfielders, and forwards, respectively (Connors et al., 2022b). These results appear favourably in comparison to the mean peak speed of backs (6.44 ± 3.0 $m \cdot s^{-1}$) recorded over 14 games in one team playing in the Women's English Premier Elite Domestic Rugby Union (Bradley, Board, Hogg, & Archer, 2020). Outside backs were reported as the fastest position with a mean peak speed of 6.92 ± 2.4 $m \cdot s^{-1}$. The fastest players by position in Australian Football League Women's (AFLW) were the small backs, reporting a mean peak speed of 7.11 $m \cdot s^{-1}$ over seven games (Clarke et al., 2018). A recent publication in ladies Gaelic football reported that the team peak speed mean was 7.17 ± 0.41 $m \cdot s^{-1}$ over 15 competitive games across two seasons (Malone et al., 2023). This result was reflective of a relative peak speed of 86 ± 4% when compared to peak speed obtained during a 40 m linear sprint test during the pre-season testing battery (Malone

et al., 2023). This result suggests that ladies Gaelic football players may not reach peak speed during match-play.

Substantial differences appear to exist between peak speeds recorded in hurling and men's Gaelic football with values ranging from 7.81 to 9.97 $m \cdot s^{-1}$ in comparison to 5.88 to 7.45 $m \cdot s^{-1}$ in camogie and ladies Gaelic football. Biological sex can play a key role in an athlete's physical aptitude and can result in men outperforming women by 10-30% depending on the athletic endeavour (Hunter et al., 2023). If only the aforementioned three field-based female team sports are considered, the homogenous results reported between them may be indicative of the lower training age relative to their male counterparts. Additionally, optimal sport- and position- specific training methods may not be well established in these sports (Clarke et al., 2018). The majority of sports science research has been conducted with male participants which fails to take into account the inherent physiological differences between the sexes (Elliott-Sale et al., 2021).

Future Research

The sprinting demands of both football codes and camogie should be investigated to identify the prevalence of peak speed exposure during match-play. There is a dearth of literature conducted on peak speed in ladies Gaelic football and camogie. Limited data exists on ladies Gaelic football, and it is recommended that the sprint profile of this cohort is investigated during match-play. Research in camogie has only been conducted at the elite level and future work is required at sub-elite and youth levels to ensure the sprinting game demands are known. All variables related to GPS methodologies included in the current review should be reported explicitly in future research. Additionally, the preceding actions players perform prior to attaining peak speed during match-play are currently unknown. Future research should seek to identify the context in which peak speed is achieved during match-play.

Limitations

This is the first systematic review to examine peak speed monitored during match-play in Gaelic games and methodological considerations when using GPS technology. The number of studies reporting position-specific peak speed values are limited. Position-specific normative values for peak speed would help inform positional requirements as well as highlight any positional-specific changes that may occur during longitudinal data collection or an intervention. Future research should seek to publish position-specific peak speed data.

CONCLUSION

Although results should be interpreted with caution, this review provides an array of peak speed data collected in hurling and men's Gaelic football. These data span various age grades, playing standards, times of season, positional standards etc. with peak speeds between 7.81 to 9.97 $m \cdot s^{-1}$ reported. Research on peak speed performance has recently begun to emerge in camogie and ladies Gaelic football with recent publications showcasing performance values ranging from 5.88 to 7.45 $m \cdot s^{-1}$. However, the systematic search of the literature resulted in a limited number of studies conducted on both codes highlighting the need for further research to be carried out to support practitioners. These normative data will give greater context to practitioners in relation to the performance of their athletes and help inform training prescription. For example, if a squad's peak speed mean appears to be much lower than values included in this paper, training prescription can be altered. More speed development work can be incorporated into the training to help bridge this performance gap such as plyometrics, sprint mechanics, resisted sprinting, and free sprinting.

ACKNOWLEDGEMENTS

The authors wish to thank TUS Midlands for their financial support via the President's Doctoral Scholarship.

DATA AVAILABILITY

The datasets utilised in this review are available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTION

All the authors contributed to the conception and design of the study. EMcG drafted the manuscript and all authors contributed to editing and revising the manuscript. All authors read and approved the final manuscript prior to submission.

SPONSORING INFORMATION

This work was supported by the President's Doctoral Scholarship at TUS.

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