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Predicting Maximal Aerobic Speed Through Set Distance Time-Trials in Camogie Players: A Pilot Study

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ABSTRACT

Set distance time-trials (TTs) have gained popularity in research and practice as a reliable method for predicting maximal aerobic speed (MAS) in field sport athletes. Therefore, the aim of this pilot study was to investigate applicable TT distances for the establishment of MAS in camogie players.

Senior club camogie players (n = 23) undertook the Yo-Yo intermittent recovery test (Yo-Yo IR1) to establish MAS, followed by participation in non-linear, continuous set distance TTs. In a randomised order, players from six balanced groups completed three different TT distances. The TT distances were 1.2 km, 1.4 km, 1.6 km, 1.8 km, 2.0 km, and 2.2 km. Bias, limits of agreement (LOA), linear regression, and bivariate correlation analysis determined the agreement between MAS and average running speed across the TT distances.

Average running speed for each TT distance was significantly lower than Yo-Yo IR1-derived MAS (bias ≥ -3.47 ± 0.43 km·h^{-1}, $P < 0.05$). The 1.2 km TT distance exhibited the least bias and narrowest LOA (-3.47 ± 0.43 km·h^{-1} [-22.16%] and ±1.68 km·h^{-1} [±10.73%], respectively). A strong (r = 0.80 [0.44 – 0.94], P = 0.001) to very strong (r = 0.98 [0.91 – 1.00], $P < 0.001$) positive correlation was found between MAS and average TT running speeds across all TT distances. MAS appeared to be best approximated by the 1.2 km TT in senior club camogie players.

Keywords: Maximal aerobic speed; Set distance time-trials; Yo-Yo intermittent recovery test – level 1.

INTRODUCTION

Camogie is a team-oriented sport that requires athletes to complete repeated, unpredictable intervals of high-intensity efforts, integrated with prolonged periods of light-to-moderate aerobic activity, dictated by the flow of the game (Duggan et al., 2020). According to Young et al. (2021) intercounty camogie players cover 5881 ± 906 metres (m) during a competitive 60-minute game, with high-speed and sprint-speed accounting for 546 ± 259 m and 183 ± 130 m, respectively. Furthermore, Connors et al. (2020) reported that camogie players achieve maximum speeds of 6.86 ± 0.35 metres per second (m·s^{-1}), with notable variations observed across playing positions.

Given the unique physiological demands of the game, camogie players must utilise all three energy pathways (phosphagen, glycolytic, and aerobic system). As a result, the assessment of aerobic performance appears indispensable (Baker and Heaney, 2015). This enables sport and exercise science practitioners to evaluate current training methodologies and ensures future training intensities are prescribed with accuracy (Heaney et al., 2009). Moreover, improving the aerobic capacity of intermittent field sport players significantly enhances performance by increasing the total distance covered by 20%, sprint count by 100%, and ball engagement by 24% during competitive match-play (Helgerud et al., 2001).

According to literature, maximal oxygen uptake (VO_2 max) is perceived as the most reliable indicator to assess aerobic performance and determine future training intensities (Heaney et al., 2009; Thron et al., 2022). VO_2 max is commonly measured via laboratory-based treadmill assessments with incremental protocols (Du et al., 2022). The determination of true VO_2 max during laboratory graded exercise tests (GXT) requires the presence of VO_2 -plateau (Thron et al., 2022), described as a VO_2 increment of less than 150 millilitres per minute ($mL\cdot min^{-1}$) during the final phase of a GXT (Astorino et al., 2005). Furthermore, research implies that achieving VO_2 max beyond the onset of VO_2-plateau requires a greater amount of anaerobic energy to various magnitudes, depending on the athlete's physiological characteristics (Petot et al., 2012). Nonetheless, once true VO_2 max values have been identified, derivatives such as velocity at VO_2 max (vVO_2 max) may be utilised to prescribe training intensities (Heaney et al., 2009).

However, despite this, laboratory-based performance assessments are time-consuming due to the application of a single athlete testing protocol, which also requires expensive and invasive equipment (Sandford et al., 2019; Bellenger et al., 2015; Lundquist et al., 2021). Consequently, these factors pose significant barriers in team sport environments that require the assessment of multiple athletes while operating with limited resources. Therefore, simplified field-based performance assessments have been designed and validated as practical alternatives. These tests enable the simultaneous testing of multiple athletes and provides a cost-effective solution (Leger and Boucher, 1980; Bangsbo et al., 2008).

Field-based performance assessments provide a measure of MAS, commonly quantified to monitor changes in aerobic performance in response to the received training stimulus and guides future training methodologies (Heaney et al., 2009; Baker and Heaney, 2015). MAS is defined physiologically as the minimum running velocity that elicits VO_2 max (Akdogan et al., 2023). Expressed as a velocity, this parameter has become an invaluable tool for sport and exercise science practitioners. Incorporating percentages of MAS allows for the precise calibration of training intensities. This facilitates the achievement and attainment of specific physiological objectives throughout the competitive season (Baker, 2011).

Among field-based performance assessments, Yo-Yo Intermittent Recovery Test – Level 1 (YoYo IR1) is one of the most exploited tests in GAA-related research to evaluate aerobic performance (Boyle et al., 2021). However, tests such as the Yo-Yo IR1, University of Montreal Track Test (UMTT), and 20 m Shuttle Run Test can be onerous in applied team-sport environments due to the substantial time and resources required, especially when field-based performance assessments must be conducted regularly to ensure accurate training intensity prescription (Bellenger et al., 2015; Lundquist et al., 2021). These constraints illustrate the need for a concise and less burdensome field-based performance assessment approach.

In recent attempts to develop resource and time efficient methods to determine MAS in field sport athletes, set distance TTs have gained popularity and approval in scientific literature and practice. Lundquist et al. (2021) established that UMTT-derived MAS was most accurately approximated by the average running speed achieved during a 1.4-1.5 km TT in female Australian football (AF) players (bias = -0.1 ± 0.3 $km\cdot h^{-1}$ [-0.9 ± 2.1%] and LOA = ±0.8 $km\cdot h^{-1}$ [±6.1%]). Alternatively, Bellenger et al. (2015) identified that the average velocity obtained during a 2 km TT distance provided the best approximation of UMTT-derived MAS in male AF athletes (bias = <0.01 $km\cdot h^{-1}$ [0.0%] and LOA = ±0.89 $km\cdot h^{-1}$ [±5.3%]). Notably, both studies implemented linear, continuous protocols across UMTT and TT assessments, providing a comparable methodological approach to evaluate the relationship between UMTT-derived MAS and TT performance.

However, despite methodological consistency, variation in UMTT protocols to determine MAS was observed between the studies. Lundquist et al. (2021) utilised an initial running velocity of 8 $km\cdot h^{-1}$. Conversely, Bellenger et al. (2015) exercised a commencing velocity of 10 $km\cdot h^{-1}$. According to the literature, slight variations in testing protocols can result in a 10% discrepancy in MAS results (Billat and Koralsztein, 1996). Nevertheless, these initial running velocities were prescribed in accordance with the physiological characteristics of the respective athlete population (Edwards et al., 2017). Consequently, it is imperative to consider gender-specific physiological differences. These include heart and lung size, blood volume, red blood cell parameters, and testosterone production, all of which enable male athletes to achieve higher MAS values (Grau et al., 2018; Bassareo et al., 2020; St Pierre et al., 2022).

Moreover, Du et al. (2022) demonstrated a 3 km TT distance (0.06 $km\cdot h^{-1}$, $P > 0.05$) best approximated

MAS derived from laboratory GXT in male collegiate runners in comparison to a 2 km TT performance (0.81 km·h^{-1}, p < 0.05). Nonetheless, Thron et al. (2022) found that a 1.5 km TT distance is not optimal for approximating laboratory GXT-derived MAS in trained male soccer players, as it led to an overestimation of MAS by 1.68 km·h^{-1} (P < 0.01). Similarly, Sandford et al. (2019) observed that the average running velocity recorded during a 1.5 km TT exceeded laboratory GXT-derived MAS by +2.06 ± 1.03 km·h^{-1} in elite male middle-distance runners. Collectively, these studies utilised linear, continuous TT protocols, with the reference measure of MAS derived from continuous GXT in controlled laboratory-based settings. However, a notable limitation in the research undertaken by Thron et al. (2022) and Sandford et al. (2019) is the evaluation of a single TT distance. Consequently, the optimal TT distance for accurately approximating laboratory GXT-derived MAS remains unknown for the respective athlete groups.

Considering camogie is distinctively unique in comparison to other female-specific team sports, and given the physiological, endocrinological and anatomical differences between genders. It is unreasonable to assume that research conducted on males or females from various sport disciplines can be directly applied in the field of camogie (Baker and Heaney, 2015). Furthermore, MAS is a derived metric that varies depending on the aerobic performance assessment utilised, with differences observed between linear continuous and non-linear discontinuous testing protocols (Buchheit, 2008). This highlights that TT distances reported in previous research are inherently limited and should only be interpreted within the context of the specific aerobic performance assessment used to derive MAS. Consequently, the optimal TT distance for the establishment of MAS in camogie players is unknown. Without this information, it is probable that current training methodologies are inadequately conditioning players for the physical demands of the sport.

Therefore, the primary aim of this study was to assess which TT distance would elicit an average running speed that best approximated Yo-Yo IR1-derived MAS in camogie players. It was hypothesised that TTs longer or shorter than the optimal distance would result in average running speeds that underestimate or overestimate MAS. Given that a 1.4-1.5 km TT distance most closely approximated MAS in elite female AF athletes (Lundquist et al., 2021). It was also hypothesised that a TT distance equal to or less than 1.4 km would elicit an average running speed best approximating Yo-Yo IR1-derived MAS in amateur camogie players.

METHODOLOGY

Participants

Twenty-six senior club camogie players (age: 23.2 ± 4.1 years; height: 173.9 ± 5.4 cm; body mass: 63.2 ± 7.0 kg) volunteered to participate in this pilot study. However, only twenty-three participants completed all testing protocols and were included in the final analysis. All participants were female, over the age of 18 years, and injury-free for two months prior to the start of testing. Participants were required to maintain their usual training regimen throughout the investigation, which included three training sessions per week. Participants with any chronic condition that might have hindered their ability to participate were excluded from the study. Prior to testing, all participants completed health screening questionnaires and consent forms, which outlined the study's objectives, benefits, procedures, and potential risks. Ethical approval was requested and authorised by SETU's Research Ethics Committee.

Experimental Design

Testing was conducted over 4 sessions (temperature: 10-14°C and humidity: 73-97%) during a 4-week period in pre-season, with each session separated by 7 days. Each testing session was performed on a natural grass pitch at Pearse Park, Dunloy, Co. Antrim. Additionally, all assessments were administered in the morning to maintain consistent environmental conditions throughout the investigation. During the initial session, participants completed the Yo-Yo IR1 test to determine MAS (Bangsbo et al., 2008). Furthermore, players' anthropometric data was collected using portable ForceDecks (model VAL002, Vald performance, Brisbane, Australia) and wireless stadiometer (model 213, Seca, Hamburg, Germany). Following the initial session, participants were randomly assigned to one of six balanced groups. This was achieved through the practice of minimisation by utilising MAS values derived from Yo-Yo IR1 (Altman and Bland, 2005). During the three TT testing sessions, each group performed one of three distinct TT distances (1.2 km, 1.4 km, 1.6 km, 1.8 km, 2.0 km, and 2.2 km). These distances were allocated using a randomised and balanced approach.

Experimental Protocol

Familiarisation session:

All participants completed a familiarisation session one week prior to data collection. This enabled participants to gain an understanding of the field-based performance tests involved in the research study.

Warm-up:

Participants completed a standardised warm-up before each session. The warm-up consisted of 5 minutes of general locomotor movements, followed by dynamic activation and mobilisation activities. Thereafter, the athletes were exposed to 5 minutes of plyometrics and running-specific movements.

Yo-Yo intermittent recovery test level 1 (Yo-Yo IR1):

The Yo-Yo IR1 protocol was implemented to determine MAS (Bangsbo et al., 2008). This intermittent test required athletes to perform 2 x 20 m shuttles at gradual increasing speeds, interspersed with a 10 second active recovery period governed by an audio cue. The assessment began with 4 running bouts covering speeds from 10 to 13 km·h^{-1} (0 - 160 m), before progressing to 7 runs at speeds corresponding to 13.5 to 14 km·h^{-1} (160 - 440 m). Thereafter, the speed increased by 0.5 km·h^{-1} after each set of 8 running bouts until the athlete reached exhaustion. The test concluded when the athlete was unable to complete the shuttle run within the allocated timeframe on two consecutive attempts.

MAS values for the Yo-Yo IR1 were determined utilising the equation proposed by Kuipers et al. (1985):

$$MAS = V + 0.5 \times (n/8)$$

Where, 'V' represents the velocity achieved at the penultimate phase, 0.5 denotes the increments in velocity at the end of each phase (measured in km·h^{-1}), and 'n' signifies the number of shuttle runs performed at each phase commencing from 14.5 km·h^{-1}.

Set Distance Time-Trial:

TT distances allocated to each group were completed by performing 100 m continuous shuttles. Participants were required to execute a 180° change of direction (COD) manoeuvre at the end of each shuttle. The shuttle track was divided into six lanes and arranged based on TT distances with training poles placed at either end (see Figure 1). During the three subsequent TT sessions, a measuring wheel (model 487XG, Forge, Shenzhen, China) was employed to accurately measure the shuttle track. Completion times for the given TT distances were recorded to the nearest second using a stopwatch (model 300, Fonza, Wrexham, England). Furthermore, a standardised correction of 0.7 seconds per COD was applied (Baker and Heaney, 2015). This data was subsequently interpreted to determine the average speed (measured in km·h^{-1}) achieved during the TT distance.

Statistical Analysis

Statistical analysis was conducted utilising SPSS (version 28, SPSS Inc., Chicago, IL). Statistical

Figure 1. Outline of the set distance TT protocol consisting of a 100-metre shuttle track divided into lanes, with training poles at either end.

significance was set at $P < 0.05$. All data were presented as mean ± standard deviation, unless otherwise specified. Normality of data was analysed using the Shapiro-Wilk test. All data were normally distributed except for group balance analysis. Thus, a Kruskal-Wallis test compared the distribution of Yo-Yo IR1-derived MAS across the six groups to confirm that all groups were balanced. A one-way ANOVA was conducted to evaluate the differences in average running speeds among the various TT distances. Effect sizes were evaluated using eta squared (η^2) and classified in accordance with Cohen (1988): 0.01 = small, 0.06 = medium, 0.14 = large. Paired-samples t-tests with Bonferroni correction compared running speeds between MAS and the various TTs. LOA analysis was employed to determine the absolute agreement between tests (Bland and Altman, 2010). Furthermore, within the LOA analysis, fixed bias was assessed via one-sample t-tests, whereas proportional bias was analysed through regression slopes (Ludbrook, 2010). Relationships between variables were determined using linear regression and bivariate correlation analysis. The values of Pearson's correlation coefficient (r) were interpreted as: negligible (0.00 - 0.29), weak (0.30 - 0.49), moderate (0.50 - 0.69), strong (0.70 - 0.89), and very strong (0.90 - 1.00) (Mukaka, 2012).

RESULTS

The final analysis included data from 23 athletes. No significant differences were found among the groups prior to the subsequent TT sessions ($P > 0.05$, see Table 1). Therefore, affirming that the groups were balanced. Table 2 presents the statistical agreement between Yo-Yo IR1-derived MAS and average running speed across the various TT distances.

From the results, a strong (r = 0.80 [0.44 – 0.94], P = 0.001) to very strong (r = 0.98 [0.91 – 1.00], P < 0.001) positive correlation was observed between Yo-Yo IR1-derived MAS and average TT speeds across all TT distances. The average running speed for each TT distance was significantly lower than Yo-Yo IR1-derived MAS (bias ≥ -3.47 ± 0.43 km·h^{-1}, P

Table 1. Distribution of mean Yo-Yo IR1-derived MAS across groups.

Group	Number of Athletes	Mean Yo-Yo IR1-derived MAS
A	3	16.21 ± 1.44 km·h^{-1}
B	4	15.60 ± 1.05 km·h^{-1}
C	3	15.56 ± 0.72 km·h^{-1}
D	4	15.33 ± 0.60 km·h^{-1}
E	5	15.45 ± 0.26 km·h^{-1}
F	4	15.33 ± 0.31 km·h^{-1}

Note: MAS: maximal aerobic speed; Yo-Yo IR1: Yo-Yo intermittent recovery test level 1.

Table 2. Agreement between Yo-Yo IR1-derived MAS and average running speed across the various TT distance.

	1.2 km	1.4 km	1.6 km	1.8 km	2.0 km	2.2 km
Athletes (n)	10	13	12	11	12	11
Time (min:s)	05:57 ± 00:35	07:05 ± 00:34	08:07 ± 00:39	09:11 ± 00:59	10:36 ± 01:00	11:53 ± 01:14
TT Speed (km·h^{-1})	12.20 ± 1.25*	11.94 ± 0.98*	11.90 ± 1.01*	11.88 ± 1.30*	11.44 ± 1.08*	11.20 ± 1.09*
Yo-Yo IR1 Speed (km·h^{-1})	15.66 ± 0.87	15.46 ± 0.58	15.60 ± 0.80	15.67 ± 0.99	15.53 ± 0.65	15.39 ± 0.50
R	0.98 (0.91 - 1.00)	0.80 (0.44 - 0.94)	0.90 (0.66 - 0.97)	0.90 (0.66 - 0.98)	0.94 (0.81 - 0.99)	0.82 (0.42 - 0.95)
Bias						
km·h^{-1}	-3.47 ± 0.43	-3.52 ± 0.63	-3.70 ± 0.46	-3.79 ± 0.58	-4.09 ± 0.52	-4.19 ± 0.74
%	-22.16	-22.77	-23.72	-24.19	-26.34	-27.23
LOA						
km·h^{-1}	±1.68	±2.46	±1.80	±2.28	±2.04	±2.90
%	±10.73	±15.91	±11.54	±14.55	±13.14	±18.84

Note: TT: time-trial; Yo-Yo IR1: Yo-Yo intermittent recovery test level 1; LOA: limits of agreement; r: Pearson's correlation coefficient; n: number of athletes.
** Significantly different from Yo-Yo IR1-derived MAS (P < 0.05).*

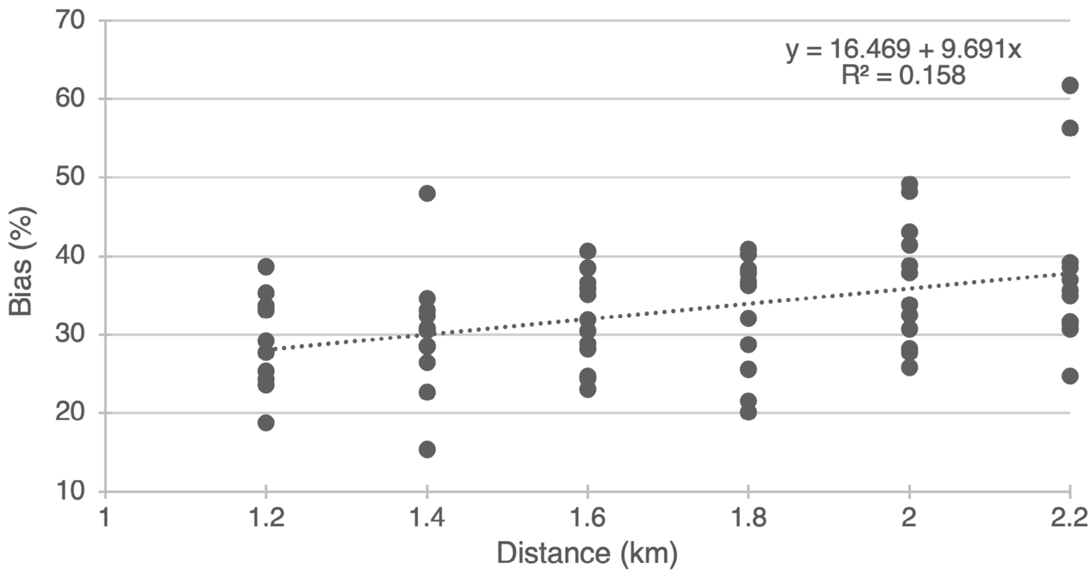

Figure 2. Agreement between Yo-Yo IR1-derived MAS and average running speed in relation to TT distance.

Table 3. Summary of linear regression analysis for predicting Yo-Yo IR1-derived MAS from running speed across the various TT distances.

Predictor	Regression Equation	R^2	*P*- value	Coefficient (β)	Standard Error	95% CI
1.2 km	y = 7.287 + 0.687x	0.958	<0.001	0.687	0.051	0.570 – 0.804
1.4 km	y = 9.859 + 0.469x	0.633	0.001	0.469	0.108	0.232 – 0.706
1.6 km	y = 7.165 + 0.709x	0.801	<0.001	0.709	0.112	0.460 – 0.958
1.8 km	y = 7.438 + 0.693x	0.816	<0.001	0.693	0.110	0.445 – 0.941
2.0 km	y = 9.056 + 0.566x	0.892	<0.001	0.566	0.062	0.427 – 0.704
2.2 km	y = 11.178 + 0.376x	0.666	0.002	0.376	0.089	0.175 – 0.577

Note: R^2: R-squared; β: beta; CI: confidence interval

< 0.05). Furthermore, no significant difference was found in the average running speeds across all TT distances: F (5, 63) = 1.18, *P* = 0.33, with a medium effect size (η^2 = 0.09). The 1.2 km TT distance exhibited the least bias and narrowest LOA (-3.47 ± 0.43 km·h^{-1} [-22.16%] and ±1.68 km·h^{-1} [±10.73%], respectively).

The LOA between Yo-Yo IR1-derived MAS and average running speed for each TT distance are illustrated in Figure 3 and 4. A significant fixed bias was detected across all TT distances (*P* < 0.001). Additionally, proportional bias was observed in the 1.2 km (beta (β) = -0.354, R-squared (R^2) = 0.758, *P* < 0.05), 1.4 km (β = -0.571, R^2 = 0.455, *P* < 0.05), 2.0 km (β = -0.515, R^2 = 0.726, *P* < 0.05), and 2.2 km (β = -0.801, R^2 = 0.686, *P* < 0.05) TT distances. However, no proportional bias was found in the 1.6 km (β = -0.245, R^2 = 0.218, *P* > 0.05) and 1.8 km (β = -0.277, R^2 = 0.281, *P* > 0.05) TT distances.

Linear regression analysis revealed a weak positive association between bias in MAS and TT distance (*r* = 0.40, *P* < 0.05; see Figure 2), characterised by a regression equation of y = 16.469 + 9.691x and an R^2 of 0.158. Despite the detected bias, the running speed derived from TT distances ranging between 1.2 and 2.2 km could be used to predict MAS by utilising the regression equations detailed in Table 3.

DISCUSSION

Given the rising popularity of camogie, the need for comprehensive research on camogie players has never been more pronounced. The main aim of this study was to establish a TT distance that would elicit an average running speed that best approximated Yo-Yo IR1-derived MAS in camogie players.

Contrary to expectations, the average running speed elicited across the respective TT distances exhibited no agreement with Yo-Yo IR1-derived MAS. Additionally, all TT distances elicited average speeds that significantly underestimated MAS (bias ≥ -3.47 ± 0.43 km·h^{-1} [-22.16%], *P* < 0.05). These findings deviate from those of Bellenger et al. (2015),

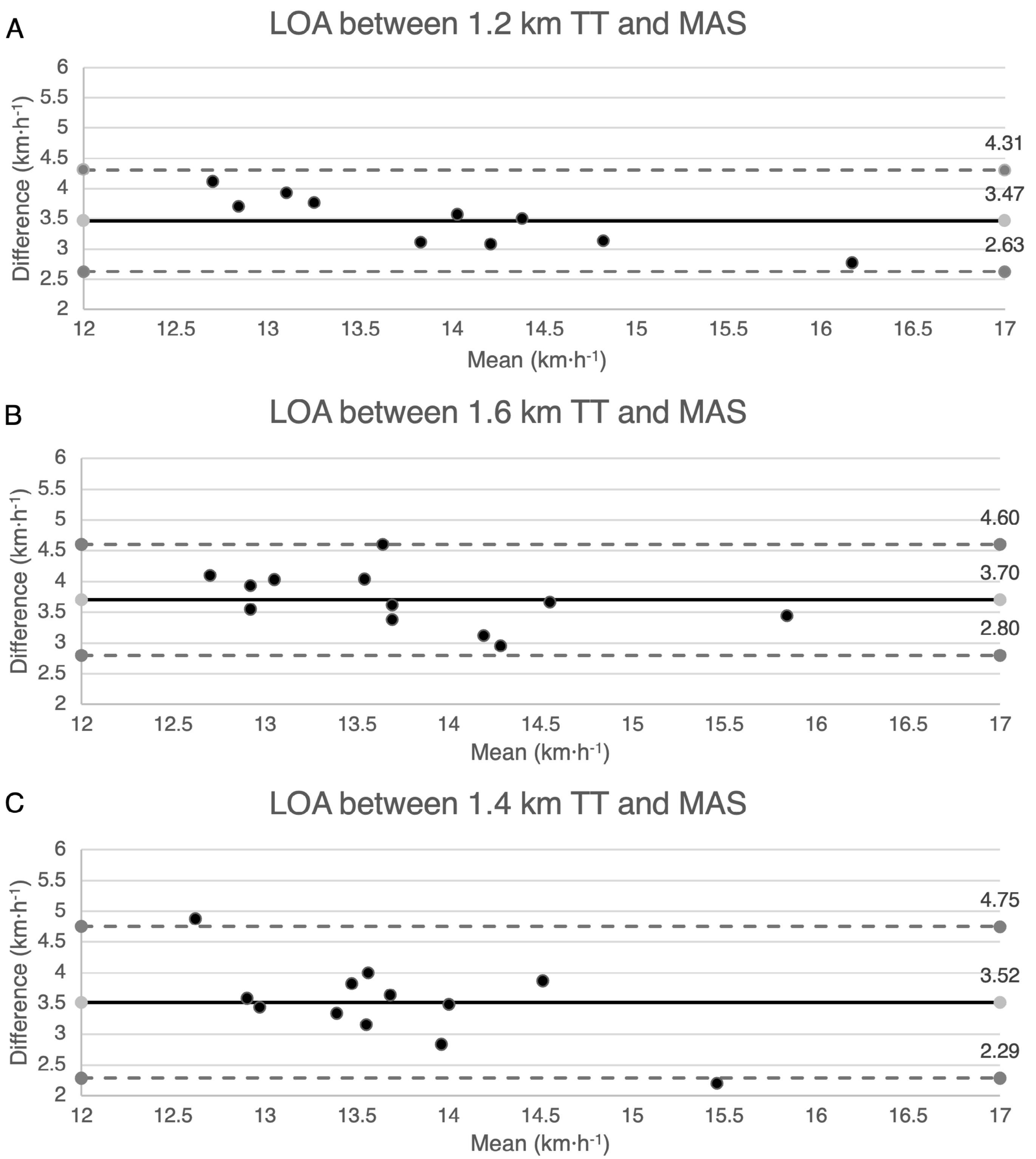

Figure 3. Bland-Altman plots for LOA analysis between (A) MAS and 1.2 km TT distance; (B) MAS and 1.4 km TT distance; and (C) MAS and 1.6 km TT distance. The continuous lines denote the average difference, while the dotted lines illustrate the LOA (±1.96 SD).

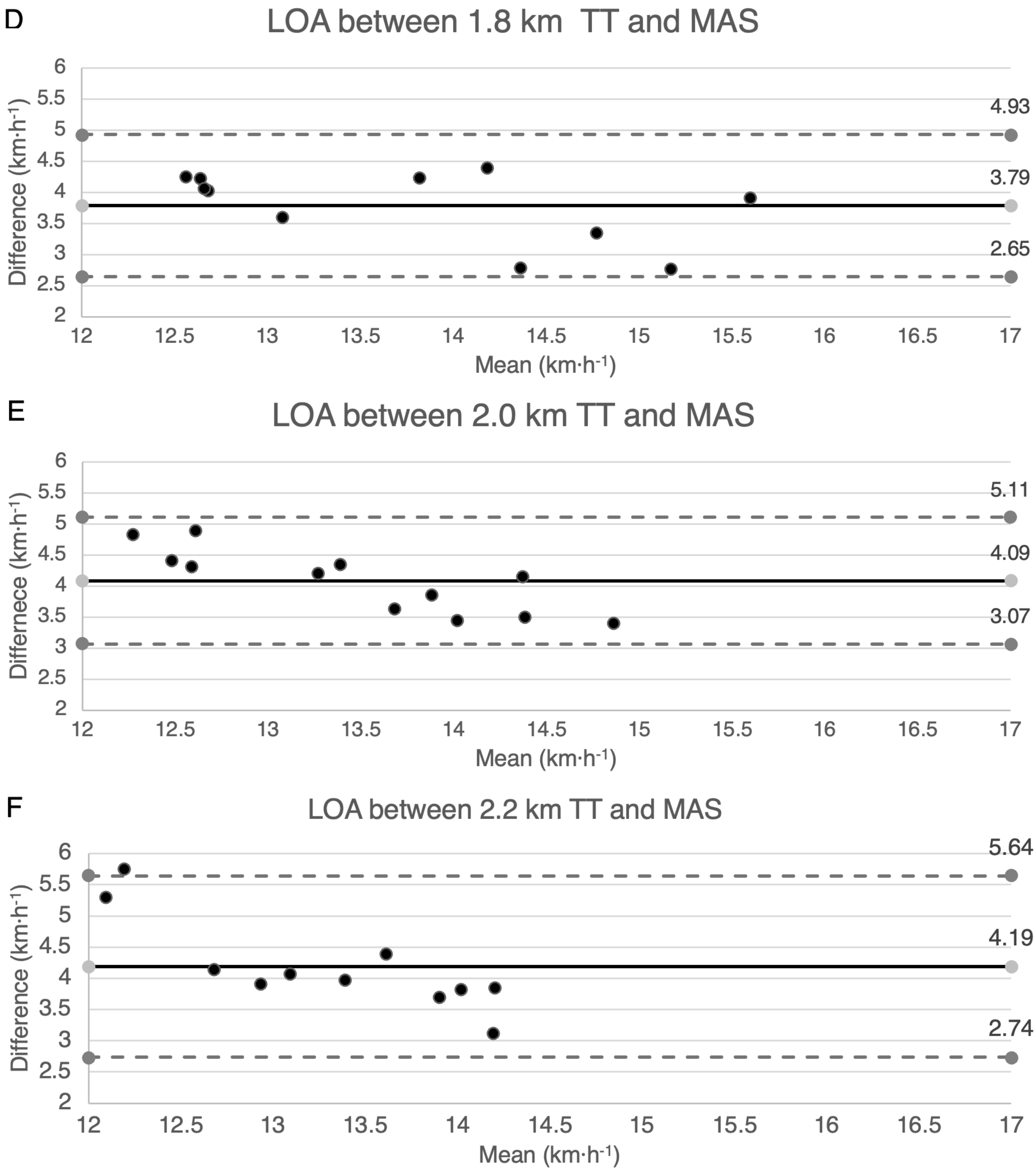

Figure 4. Bland-Altman plots for LOA analysis between (D) MAS and 1.8 km TT distance; (E) MAS and 2.0 km TT distance; and (F) MAS and 2.2 km TT distance. The continuous lines denote the average difference, while the dotted lines illustrate the LOA (±1.96 SD).

who demonstrated UMTT-derived MAS could be accurately approximated by the average running speed elicited during the optimal TT distance in male AF players (bias < 0.01 km·h^{-1} [0.0%], P > 0.05). Similarly, Lundquist et al. (2021) found that the average running speed achieved during the optimal TT distance successfully approximated UMTT-derived MAS in female AF athletes (bias = -0.1 ± 0.3 km·h^{-1} [-0.9 ± 2.1%], P > 0.05).

The observed discrepancies in MAS values between Yo-Yo IR1 and TT distances can be attributed to inherent differences in test methodologies. Research indicates these discrepancies are largely due to the Yo-Yo IR1 structured intermittent recovery intervals (Akdogan et al., 2023). This allows athletes to partially resynthesize energy substrates and facilitates the clearance of metabolic byproducts (Rogers et al., 2024). Therefore, enhancing the athletes' capacity to sustain elevated speeds throughout the test. Conversely, set distance TTs do not provide recovery periods, which compels athletes to maintain a continuous steady state of exertion (Dupont et al., 2010). Therefore, MAS values obtained from Yo-Yo IR1 should not be considered interchangeable with set distances TT results, due to fundamental differences in physiological demands and performance outcomes between the tests (Heaney et al., 2009).

Despite the observable bias, the average TT speed attained during the 1.2 km TT best approximated Yo-Yo IR1-derived MAS in camogie players, exhibiting the smallest bias and narrowest LOA (-3.47 ± 0.43 km·h^{-1} [-22.16%] and ±1.68 km·h^{-1} [±10.73%], respectively). Aligned with the hypothesis, this distance was shorter than the 1.4–1.5 km TT, which best approximated MAS in female AF players (Lundquist et al., 2021). This illustrates the critical significance of sport-specific research when considering the application of TTs to evaluate aerobic performance and prescribe accurate training intensities. However, considering the methodological differences between Yo-Yo IR1 and TT distances, the 1.2 km TT likely imposed less physiological strain compared to the other TT distances (Esteve-Lanao et al., 2008). This reduced strain may have contributed to the least bias and narrowest LOA observed.

Nonetheless, the finding of the 1.2 km TT distance being optimal for the determination of MAS in camogie players aligns with the established duration threshold for MAS. Research indicates that MAS duration limit ranges from 5:00 to 8:42 min:s (Lacour et al., 1990; Billat et al., 1999; Dupont et al., 2002; Baker and Heaney, 2015). In the current study, the completion time for the 1.2 km TT was 05:57 ± 00:35 min:s.

Moreover, within this specified MAS duration, Lundquist et al. (2021) found elite female AF players covered distances between 1.4–1.5 km, surpassing the 1.2 km achieved by amateur camogie players in this study. This finding corresponds with Baker and Heaney (2015), who reported that professional female athletes obtain higher MAS values compared to their semi-professional and amateur peers. This can be attributed to the higher training loads typically endured by professional athletes, which likely enhances their aerobic capacity and overall athletic performance (Al-Attar et al., 2020).

However, direct comparisons should be interpreted with caution due to methodological differences, as MAS values obtained in this study were derived using non-linear, continuous TT protocols. Research has indicated the inclusion of COD manoeuvres significantly enhances physiological and metabolic load compared to linear running performance, due to repeated accelerations and decelerations. According to Gribben et al. (2021), non-linear running protocols are approximately 30 - 50% more energetically demanding than continuous linear running at equivalent speeds. These elevated energetic demands are attributed to repeated eccentric contractions of the lower limbs and increased upper-body involvement during COD movements, which contribute to increased hamstring muscle deoxygenation, blood lactate and heart rate (Dellal et al., 2010).

Furthermore, gender-specific physiological differences, such as variations in stroke and tidal volume, total blood volume, haemoglobin concentration, haematocrit, and testosterone production, enable male athletes to achieve superior MAS values compared to their female counterparts (Grau et al., 2018; Bassareo et al., 2020; St Pierre et al., 2022). The present study supports these physiological distinctions, with male AF athletes achieving a significantly greater distance of 2.0 km within the MAS duration threshold (Bellenger et al., 2015). In addition, these findings support the concept that performance capacity is duration dependent as opposed to distance dependent (Billat and Koralsztein, 1996).

In this study, a strong (r = 0.80 [0.44 – 0.94], P = 0.001) to very strong (r = 0.98 [0.91 – 1.00], P <

0.001) positive correlation was observed between MAS and average TT speeds across all TT distances. This observation is intuitive, considering that all six TT distances selected to determine MAS demanded maximal efforts ranging from 05:57 ± 00:35 to 11:53 ± 01:14 min:s. These durations are known to induce significant levels of aerobic power (Dupont et al., 2002; Caputo and Denadai, 2008; Penry et al., 2011). Consequently, given that research has established field-based performance assessments of MAS can elicit VO_2 max (Leger and Boucher, 1980; Bangsbo et al., 2008), it is understandable that TTs requiring a substantial contribution of aerobic power exhibit a strong correlation with MAS.

Furthermore, this study identified a positive linear association between TT distance and the extent of bias between MAS derived from a Yo-Yo IR1 and average running speed. The average running speed achieved during the 1.2 km TT distance provided the closest approximation of MAS (bias = -3.47 ± 0.43 km·h^{-1} [-22.16%], LOA = ±1.68 km·h^{-1} [±10.73%], $P < 0.05$). This underestimation increased progressively with each additional 200 m increase in TT distance, with the 2.2 km TT distance demonstrating the greatest underestimation of MAS (bias = -4.19 ± 0.74 km·h^{-1} [-27.23%], LOA = ±2.90 km·h^{-1} [±18.84%], $P < 0.05$). These findings concur with Lundquist et al. (2021), who observed similar results for comparable TT distances, with the 2.2 km TT exhibiting the highest magnitude of bias (bias = -1.00 ± 0.30 km·h^{-1} [-7.6 ± 2.6%], LOA = ±0.80 km·h^{-1} [±6.70%], $P < 0.05$). This highlights the critical importance of establishing the appropriate TT distance to accurately determine MAS within a specific athletic cohort. Moreover, the use of inappropriate TT distances results in suboptimal training regimens that inadequately condition athletes for competitive match-play, while potentially increasing the risk of injury (Heaney et al., 2009).

However, it is important to note that the linear regression analysis indicated Yo-Yo IR1-derived MAS could be determined from TT distances ranging between 1.2 km and 2.2 km using the available regression equations. Nonetheless, it is important to acknowledge that these regression equations may not be entirely accurate due to the presence of systematic bias between the Yo-Yo IR1 and TT distances. Notably, although the 1.6 km and 1.8 km TT distances (-3.70 ± 0.46 km·h^{-1} [-23.72%] and -3.79 ± 0.58 km·h^{-1} [-24.19%], respectively) exhibited greater systematic bias compared to the 1.2 km and 1.4 km TT distances (-3.47 ± 0.43 km·h^{-1} [-22.16%] and -3.52 ± 0.63 km·h^{-1} [-22.77%], respectively), no proportional bias was present ($P > 0.05$). These findings were reinforced by the fact that the 1.4 km TT distance exhibited the second widest LOA (±2.46 km·h^{-1} [±15.91%]), subsequent to the 2.2 km TT distance (±2.90 km·h^{-1} [±18.84%]), despite the 1.2 km TT distance providing the best approximation of MAS (Giavarina, 2015). Therefore, the regression equations derived from both the 1.6 km and 1.8 km TT distances are likely to be more reliable for predicting MAS, as these equations are less influenced by performance variations (Ludbrook, 1997). Nevertheless, further research is warranted to refine the regression equations obtained in the study to enhance their precision and reliability.

A limitation in this research study was the utilisation of a single field-based performance assessment to derive the criterion measure of MAS. Within this current study, MAS was determined using the Yo-Yo IR1, a discontinuous incremental test performed until volitional exhaustion (Bangsbo et al., 2008). However, alternative field-based performance assessments with continuous incremental protocols have illustrated that MAS can be accurately predicted from the average running speed attained over the optimal TT distance (Bellenger et al., 2015; Lundquist et al., 2021). This indicates that continuous incremental protocol tests provide a more effective methodological approach to determine the optimal TT for predicting MAS, as such assessments mitigate bias and offer a more precise approximation.

Although field-based performance assessments provide a measure of MAS, evaluating a single parameter provides limited insight into the determinants that influence test performance. Thus, consideration of the athletes' anaerobic speed reserve (ASR) may provide a more comprehensive understanding of their physiological and neuromuscular profile, which contributes to their ability to perform and sustain high-speed efforts (Thron et al., 2024). ASR is defined as the difference between MAS and maximal sprint speed (MSS), enabling athletes to be categorised into three distinct locomotor profiles (Sandford et al., 2021). These include sprint athletes (high ASR, high MSS, low MAS), endurance athletes (low ASR, low MSS, high MAS), and hybrid athletes (moderate ASR, moderate MSS, moderate MAS) (Thron et al., 2024).

When examined within intermittent testing protocols (e.g. Yo-Yo IR1), athletes with lower ASR and MSS demonstrate greater neuromuscular strain and heightened biochemical responses compared with those exhibiting higher ASR and MSS (Thron et al., 2024). This response is likely due to athletes with higher ASR and MSS possessing a greater proportion of fast twitch fibres, which may enhance their tolerance to metabolic acidosis (Parkhouse et al., 1985). In contrast, hybrid and endurance-oriented athletes demonstrate superior performance in continuous testing protocols compared to sprint-oriented athletes, which may be related to differences in muscle fibre composition, with slow twitch fibres being associated with greater mechanical efficiency and running economy during sustained aerobic activity (Van Der Zwaard et al., 2021; Thron et al., 2024). Consequently, locomotor profile differences among camogie players may influence performance in field-based performance assessments, with MAS values potentially varying within-subject depending on whether continuous or discontinuous protocols are employed. This highlights the practical utility of locomotor profiling, enabling coaches to interpret aerobic performance assessment results with greater insight and prescribe training interventions specific to each athlete's profile to maximise training adaptations while reducing the likelihood of maladaptive responses and overreaching (Sandford et al., 2021).

Given that MAS is a contrived variable influenced by the assessment employed, the agreement between TT performance and the reference measure of MAS observed in the current study should be considered exclusively within the context of Yo-Yo IR1. According to Billat and Koralsztein (1996), it is imperative sport and exercise science practitioners acknowledge that the application of different field-based performance assessments can induce variations in MAS outcomes by 10%. Nevertheless, the utilisation of a standardised TT distance for approximating MAS over consecutive assessments will enable practitioners to accurately detect changes in aerobic performance and evaluate current training practices.

Furthermore, the findings from this study are specific to senior club camogie athletes. Considering the variability in MAS values reported across various team sports and levels of participation, these results should not be applied beyond the context of senior club camogie players (Baker and Heaney, 2015). Therefore, future research should explore the extent to which these findings apply to the various participation levels in camogie, aiming to determine the optimal TT distance for quantifying MAS across each competition level.

Moreover, data collection was conducted in a practical environment. This augments the ecological validity of the study. Nonetheless, day-to-day environmental variations may have affected the study's outcomes. One of the four testing sessions endured elevated wind levels relative to the average conditions, which may have impacted TT performance. However, the athletes conducted their TTs in a randomised sequence, which effectively balanced the influence of environmental conditions across the various TT distances.

In conclusion, the current study revealed systematic bias between Yo-Yo IR1-derived MAS and TT performance. Despite this limitation, the average running speed elicited during the 1.2 km TT distance demonstrated the smallest bias, narrowest LOA, and strongest correlation when compared with Yo-Yo IR1-derived MAS. Thus, demonstrating a 1.2 km TT distance may be best suited for the determination of MAS in senior club camogie players to assess training-related adaptations in aerobic performance and assign individualised training intensities. Nevertheless, caution is warranted, as this distance did not provide a completely accurate approximation of MAS. Future research should further investigate set distance TTs for predicting MAS in this homogeneous group by utilising field-based performance assessments with continuous incremental protocols to derive the criterion measure of MAS.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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ETHICAL APPROVAL

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