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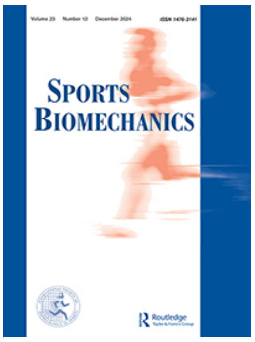

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Agreement between an automated video-based system and tethered system to measure instantaneous swimming velocity

Michelle Scott[a], Nathan Elsworthy[a], Victoria Brackley[b], Marc Elipot[c] and Crystal O. Kean[a,d]

[a]School of Health, Medical and Applied Sciences, Central Queensland University, Mackay, Queensland, Australia; [b]Victorian Institute of Sport, Melbourne Victoria, Australia; [c]Swimming Insight, Swimming Australia, Canberra, Australian Capital Territory, Australia; [d]Research Institute for Sport and Exercise, Faculty of Health, University of Canberra, Canberra, Australian Capital Territory, Australia

ABSTRACT

Successful performance in competitive swimming requires a swimmer to maximise propulsion and minimise drag, which can be assessed using instantaneous swimming velocity. Many systems exist to quantify velocity, and therefore, it is important to understand the agreement between systems. This study examined the agreement between an automated video-based system and a tethered system to measure instantaneous velocity. Twenty-two competitive swimmers (state level or higher) completed 25 m of each stroke at maximal intensity. The tethered speedometer was attached to the swimmer's waist, while videos of each trial were recorded. The swimmer's head was then automatically tracked using proprietary software, and instantaneous velocity was determined from each system. Bland-Altman plots showed good agreement between the two systems in backstroke (95% Limits of Agreement (LOA): −0.24–0.26 $m.s^{-1}$) and freestyle (95% LOA: −0.36–0.38 $m.s^{-1}$) but poorer agreement in butterfly (95% LOA: −0.51–0.53 $m.s^{-1}$) and breaststroke (95% LOA: −0.88–0.92 $m.s^{-1}$). The root mean square error was higher in butterfly (0.27 $m.s^{-1}$) and breaststroke (0.46 $m.s^{-1}$) compared to backstroke (0.13 $m.s^{-1}$) and freestyle (0.19 $m.s^{-1}$). Results demonstrated that the two systems are comparable for measuring instantaneous swimming velocity; however, larger discrepancies are evident for butterfly and breaststroke.

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Instantaneous swimming velocity; performance analysis; competitive swimmers; automated systems

Introduction

Successful performance in competitive swimming is highly dependent on an efficient stroke technique that maximises propulsion and minimises drag (Truijens & Toussaint, 2005). The net effect of propulsive and drag forces acting on a swimmer can be assessed from intra- and inter-cyclic velocity variations derived from instantaneous velocity

CONTACT Crystal O. Kean crystal.kean@canberra.edu.au

(A. C. Barbosa et al., 2019; Elipot et al., 2019). For example, lower intra-cyclic velocity variations indicate increased swimming efficiency as the deceleration between successive propulsive phases is minimal (Seifert et al., 2010). Conversely, larger intra-cyclic velocity variations are associated with increased energy costs and suggest an inefficient stroke technique (T. M. Barbosa et al., 2006). Inter-cyclic velocity variations, on the other hand, provide insights into the effects of arm-leg coordination on propulsive continuity (Elipot et al., 2019). Therefore, it is important that instantaneous swimming velocity can be measured in training and competition to enable swimming technique and performance to be assessed.

Historically, tethered speedometers have been used to measure instantaneous swimming velocity in the four strokes (Alberty et al., 2005; Chollet et al., 2004; Clément et al., 2021; Craig & Pendergast, 1979; Craig et al., 2006; Leblanc et al., 2007; van Houwelingen et al., 2018). Tethered speedometers typically consist of a tachometer and a spooled with a non-stretchable nylon line positioned at the end of the pool (Dadashi et al., 2013; Nofal et al., 2016). The distal end of the nylon line attaches to a belt which is firmly placed around a swimmer's waist (Dadashi et al., 2015). Instantaneous velocity is calculated from the displacement and rotational speed of the line as the swimmer moves in the forward direction (Dadashi et al., 2013; van Houwelingen et al., 2018). As such, velocity can only be measured during a single lap as the swimmer moves away from the speedometer (Mooney, Corley, Godfrey, Osborough, et al., 2016). Tension is typically applied to the tether to prevent slack from developing during stroke decelerations, which may impact the accuracy of velocity measurements during this period of time (Clément et al., 2021; Dadashi et al., 2012; Tella et al., 2008). An additional limitation of tethered systems relates to swimmers kicking too close to the tether, which can lead to erroneous velocity measurements at the data points where the artefacts occur (Stamm et al., 2013). Furthermore, the use of tethers in competition is not permitted (World Aquatics, 2023) thus the system can only be used to measure instantaneous velocity during training.

Video-based systems are commonly used in training and competition to assess swimming performance given their versatility to be positioned above and below the water (Mooney et al., 2015). Swimming performance is recorded and post-processed using dedicated computer software to track a swimmer's location over time (T. M. Barbosa et al., 2021). Swimmers are usually tracked using visible markers placed at specific anatomical landmarks such as the shoulder, elbow, wrist, hip, and knee (T. M. Barbosa et al., 2021; Psycharakis & Sanders, 2008). To calculate instantaneous velocity estimation, the change in location of the tracking landmark and time is recorded frame-by-frame throughout an entire cycle or segment sequence (Elipot et al., 2019; Magalhaes et al., 2013). Historically, the tracking of a swimmer required manual digitisation; however, modern day systems can assist with automate the digitisation process reducing the time-demands of the post-processing (Benarab et al., 2020; Gonjo & Olstad, 2021; Hall et al., 2021).

One particular automated video-based system (DeepDASH) is capable of measuring the instantaneous swimming velocity of multiple swimmers simultaneously in training and competition (up to 10 lanes) across all four strokes (Elipot et al., 2019; Hall et al., 2021). The system utilises a series of computer vision and calibration algorithms to automatically track and localise the head of a swimmer in real-world coordinates (Hall et al., 2021). Based on this technology, users can access the instantaneous swimming velocity of swimmers in every stroke and competition distance (Elipot et al., 2019; Hall et al., 2021). Previous results have shown that the DeepDASH is accurate at performing stroke detection (overall F1 score = 97.4% (ranging from a low of 94.9% (butterfly) to 98.5% (freestyle)) (Hall et al., 2021). While this automation of stroke detection has led to video-based systems being less time-consuming, results cannot be provided in real-time, resulting in delayed feedback to coaches and swimmers (Mooney, Corley, Godfrey, Osborough, et al., 2016).

As the two systems have their own advantages and disadvantages, coaches and swimmers may need to use a combination of systems throughout a competition season. For example, they may use the tethered system to provide real-time feedback during training, and a video-based system to provide feedback on competition performance. A key difference between these systems is that instantaneous swimming velocity may be measured from different body segments. Notably, the tethered speedometer measures velocity from a swimmer's hip (Alberty et al., 2005; Chollet et al., 2004; Clément et al., 2021; Craig & Pendergast, 1979; Craig et al., 2006; Leblanc et al., 2007; van Houwelingen et al., 2018), whereas the automated video-based system tracks a swimmer's head (Hall et al., 2021). This disparity in measurement sites could lead to differences in velocity measurements, which can be problematic for swimmers and coaches who may use a combination of systems to assess performance. Whenever different systems/methods are used to calculate an outcome measure (such as instantaneous swimming velocity), it is important to understand the measurement agreement, such that informed evaluation of the swimmer's performance can be made. Therefore, the aim of this study was to examine the agreement between the DeepDASH automated video-based system and a tethered speedometer to measure instantaneous swimming velocity in the four strokes. It is hypothesised that there will be good agreement between systems across strokes.

Materials and methods

Study design

A cross-sectional study design was used to examine the agreement between an automated video-based system and a tethered speedometer to measure instantaneous swimming velocity in the four strokes. All procedures were approved by the Central Queensland University Human Research Ethics Committee.

Participants

Swimmers from a regional Australian club who were aged 12 years or older and had competed at an Australian State level competition in the current or previous swimming season (i.e., 2021/2022 or 2020/2021) were invited to participate in this study. Swimmers were excluded if they were injured or had a medical condition that prevented them from undertaking high-intensity exercise as determined by stage one of the Pre-Exercise Screening Tool for Adults (18+ years) or Young People (5–17 years) (Exercise and Sports Science Australia [ESSA], 2021). Twenty-two swimmers volunteered to participate in this study. Prior to participation, swimmers (and parents of those under the age of 18 years) were informed of the study aims, procedures, benefits, and risks, and provided

Table 1. Participant demographic and training characteristics. Data presented as mean ± standard deviation (range), unless specified.

Sex (n, %)	
Male	7 (32%)
Female	15 (68%)
Age, yrs	14.5 ± 2.5 (12 – 23)
Height, m	1.68 ± 0.09 (1.56 – 1.83)
Mass, kg	63.3 ± 10.5 (47.9 – 87.1)
Number of years competitive swimming, yrs	5.8 ± 2.6 (1 – 12)
Number of training sessions per week	8.0 ± 1.5 (5 – 12)
Duration of training sessions, hrs	1.9 ± 0.2 (1.5 – 2.5)

written informed consent. At the time of data collection, all swimmers had previously competed at a minimum State level, while nine had competed at National level, and one had competed at an international level. Table 1 provides a summary of participant demographic and training characteristics.

Procedures

Demographic assessment and data collection were conducted on separate occasions at a 50 m outdoor, covered pool where the participants regularly trained. The demographic assessment collected age, body mass (electronic scales, BWB-600, Tanita Corporation, 135 Tokyo, Japan), stature (portable stadiometer, Seca 213, Seca GMBH, Hamburg, Germany), and training history. Data collection took place during the swimmer's regular training session and fit around the club/swimmers availability. Therefore, data collection took place over four days (15–18 March 2022) with three data collection sessions during the morning training sessions (530 am to 730 am; $n = 16$) and one data collection session during an afternoon training session (4 pm to 630 pm; $n = 6$). No restrictions were placed on the swimmers training in the days prior to data collection.

During the data collection session, participants were allocated into testing pairs with the order as allocated by the club's head coach. This decision was made to limit our impact on the swimmer's training session. Swimmers completed an in-pool swim-specific warm-up prescribed and delivered by their head coach. Given the swimmers varied in chronological and training ages, as well as stroke and distance specialisation, it was deemed that a 'one size fits all' approach was not appropriate, and that the warm-up would be specific to the swimmer. However, the coach's aim of the warm-up was consistent and that was to prepare the swimmers to perform 25 m maximal effort sprints across each stroke. For the testing, a Velcro belt was firmly positioned around the waist of the participant. The nylon line of the tethered speedometer was securely fastened to the belt by a clip and positioned at the central point of the lumbar region for butterfly, breaststroke, and freestyle (A. C. Barbosa et al., 2021), and the central point of the abdominal region for backstroke. As familiarisation to swimming with the tether, the participant performed two, 25 m moderate intensity trials (i.e., one freestyle and one backstroke) starting from an in-water push off the wall. After completing the two practice trials, the participant removed the Velcro belt and moved into the adjacent lane of the pool to enable the second participant to undergo the same process as described for the first participant.

Following completion of the practice trials, each participant performed one, 25 m swimming trial at maximal intensity for each stroke. Trials were performed in individual medley order (i.e., butterfly, backstroke, breaststroke, and freestyle). Participants within the pair alternated between the trials of each stroke. When not performing a swimming trial, the participant rested in the water of the adjacent swimming lane. A minimum of 2-min rest was provided; however, in some instances a longer rest was provided dependent on speed of other swimmer within the testing pair, and equipment set-up between swimmers (i.e., removing and reattaching teether). For each trial, the participant was instructed to begin in the water and reduce the glide at the start to maximise the distance of free swimming (i.e., the swimming strokes performed outside of the start, turn, and finish segments of a race) (Mooney, Corley, Godfrey, Quinlan, et al., 2016). The participant returned to the start after each trial by swimming a stroke of their choice at light intensity.

Data collection

The tethered speedometer was positioned on pool deck adjacent to the starting block of the testing lane (Figure 1) and connected to a computer with custom measurement software installed (RX Swim Capture App V21.10.30.0, AMR Sport, Parkwood, Australia). The software recorded and saved instantaneous swimming velocity measurements in database files (.dbf). The sampling frequency varied based on the rotational speed of the tachometer shaft (i.e., the faster a swimmer's velocity, the higher the tachometer/sampling frequency).

A single, fixed, ultra-high definition (UHD) camera (resolution 3840 × 2160; Canon EOS C200, Canon Australia Proprietary Limited, Sydney, Australia) with a wide-angle lens (Canon EF-S 10–22 mm, Canon Australia Proprietary Limited, Sydney, Australia)

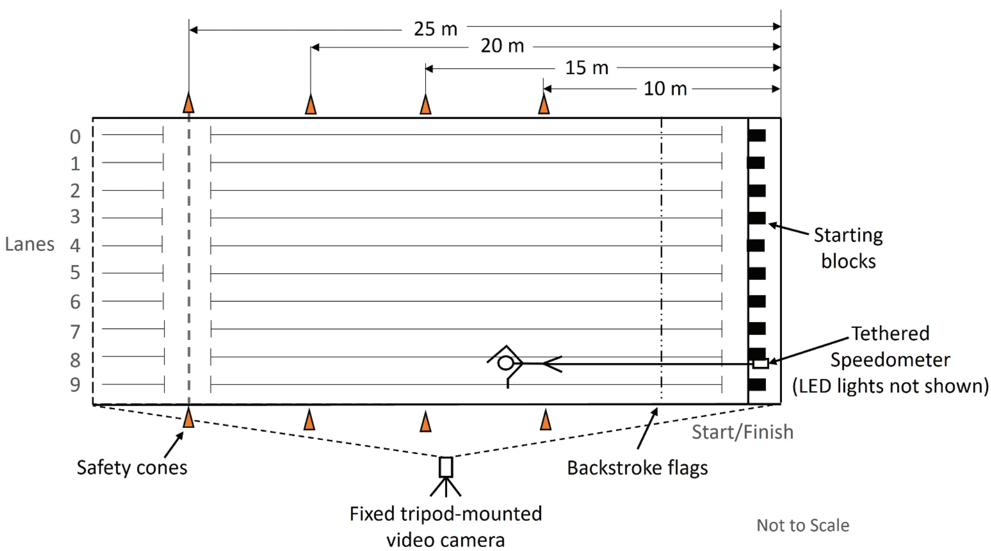

Figure 1. Experimental setup for instantaneous swimming velocity data collection at a 50 m outdoor covered pool. Abbreviation: LED, light-emitting diode.

recorded videos of all maximal intensity swimming trials at a sampling frequency of 50 Hz (Elipot et al., 2019). As highlighted by Elipot et al. (2019) and Hall et al. (2021), the automated track system's accuracy is not impacted by the camera location; therefore, the general positioning was to mount the camera on a tripod (extended to ~2.0 m) and positioned at the highest level of the adjacent grandstand (between 15 and 20 m from start) to ensure the entire swimming trial (25 m) could be captured in the field of view. Orange safety cones (30 cm high) were placed on each side of the pool at 10 m, 15 m, 20 m, and 25 m from the starting end to calibrate the two-dimensional video recordings to real-world coordinates for instantaneous swimming velocity calculations (Hall et al., 2021). The backstroke flags installed 5 m from the starting end were also used to calibrate the camera (Figure 1).

Two white light-emitting diode (LED) lights connected to the tethered speedometer were positioned in the field of view of the video camera to synchronise data from the camera and the tethered speedometer. One LED light was positioned on the platform of the starting block in the pool lane where the trials were performed. The second light was positioned on pool deck at the base of the same starting block. Both lights were activated by clicking 'Start Recording' on the measurement software installed on the computer connected to the tethered speedometer.

Data analyses

Post-processing software (MotionStudio SwordFish Edition V21.2.27.0, AMR Sport, Parkwood, Australia) converted the raw database files (.dbf) from the tethered speedometer to comma-separated (.csv) files for further analysis. Thereafter, the data were resampled to 50 Hz by cubic spline interpolation in Matlab® (R2022a, The MathWorks, Inc., Natick, Massachusetts, United States) to match the sampling frequency of the automated video-based system. Residual analyses were performed to determine the most appropriate cut-off filtering frequencies for each trial, and an average cut-off frequency was determined for each stroke (Winter, 2009). Consequently, velocity data from the tethered speedometer were filtered using a third-order Butterworth filter with cut-off frequencies of 9 Hz for backstroke and 10 Hz for butterfly, breaststroke, and freestyle. The video frame in which the LED lights were activated was identified as the zero point for each trial to synchronise instantaneous velocity data from the tethered speedometer and the automated video-based system. Using proprietary software, the two-dimensional image-space of the video recordings was calibrated to real-world coordinates (Hall et al., 2021). The Deep Detector for Actions and Swimmer Heads (DeepDASH) algorithm and the Hierarchical Simple Online and Realtime Tracking (HISORT) algorithm were applied to automatically detect and track the swimmers as outlined in Elipot et al. (2019) and Hall et al. (2021). Processed data included instantaneous swimming velocity in the horizontal direction (i.e., along the swimming lane) (Hall et al., 2021). Video-based velocity data were filtered using a third-order Butterworth filter with cut-off frequencies of 7 Hz for backstroke and freestyle, 8 Hz for butterfly, and 9 Hz for breaststroke. These cut-off frequencies were based on the average cut-off frequencies determined from residual analyses of 20 sprint distance (<200 m) races of each stroke.

Processed data from the tethered speedometer and automated video-based system were exported in Microsoft Excel (.xlsx) format. A region of interest was selected from each trial that corresponded to the times that the automated video-based system recorded velocity at the 10 m and 20 m marks. This region of interest mitigated the effects of the push off the wall and initial underwater glide at the start and any potential deceleration at the end of the 25m trial. Velocities from both systems at each sampling point between these times were used for statistical analyses.

Statistical analyses

Bland-Altman analysis (Bland & Altman, 1986) was used to examine the bias and limits of agreement (LOA) between the automated video-based system and tethered speedometer to measure instantaneous swimming velocity in the four strokes. First, plots of the difference between the two systems against the average of the two systems were constructed. Simple linear regressions were the conducted to examine the relationship between differences and average values. Given the weak relationships were found (R^2 values ranged from 0.01 to 0.24), bias was determined as the mean difference between systems, while the 95% LOA were defined as the mean difference ±1.96 SD of the mean difference (Bland & Altman, 1986). To further examine agreement between systems, the root mean square error (RMSE) was calculated as the square root of the average squared differences between the paired measurements. All statistical analyses were performed in Microsoft Excel 365 (Microsoft Office 365, Microsoft Corporation, Redmond, Washington, United States).

Results

On average, instantaneous swimming velocities were compared on 9580 data point pairs for each stroke (minimum 8177 data point pairs [freestyle] maximum 11,894 data points pairs [breaststroke]). The mean (SD) velocity across the 10 m distance analysed was 1.36 (0.13) m/s for freestyle, 1.15 (0.14) m/s for backstroke, 0.94 (0.14) m/s for breaststroke, and 1.24 (0.16) m/s for butterfly. Figure 2 shows the velocity-time profiles from the automated video-based system and tethered speedometer for each stroke from representative swimmers. The Bland-Altman plots are presented in Figure 3. Based on the bias values, the automated video-based system overestimated instantaneous swimming velocity in all the strokes compared to the tethered speedometer with the largest bias reported in breaststroke (Table 2). The widest LOA and largest RMSE were in breaststroke, while the narrowest LOA and smallest RMSE were in backstroke (Table 2).

Discussion and implications

This study examined the agreement between an automated video-based system and tethered speedometer to measure instantaneous swimming velocity in the four swimming strokes. While the bias was similar between strokes (within 0.02 $m.s^{-1}$), differences were noted in the 95% LOA and RMSE. Specifically, the LOA and RMSE were lower for backstroke and freestyle compared to butterfly and breaststroke. Based on these results, it was determined that there was good agreement between the automated video-based system and tethered speedometer for instantaneous velocity measurement in backstroke and freestyle, but poorer agreement in butterfly and breaststroke.

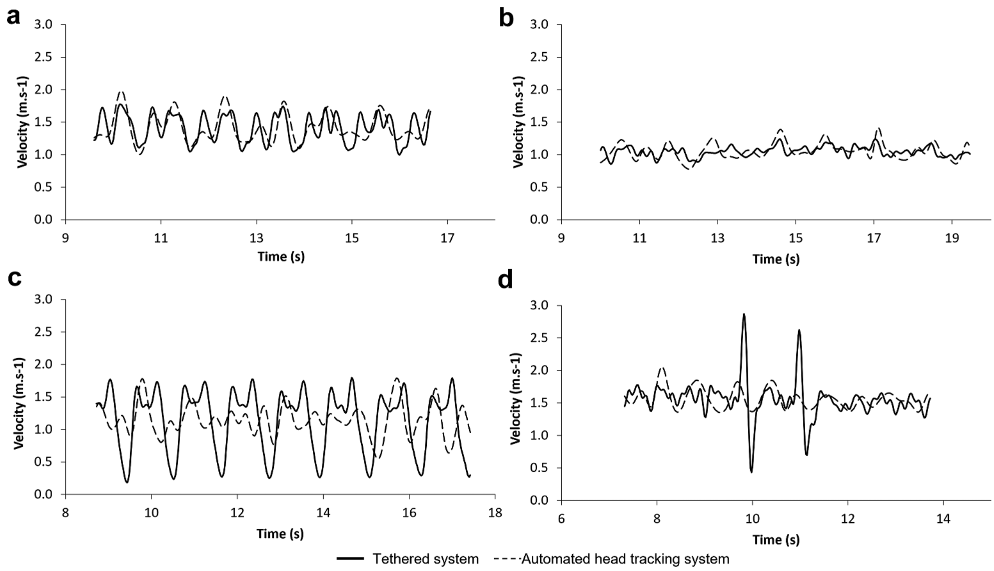

Figure 2. Filtered instantaneous swimming velocity-time profiles from the automated video-based system (dashed line) and tethered speedometer (solid line) for each stroke from representative swimmers (a: butterfly, b: backstroke, c: breaststroke, and d: freestyle). Start and end time is when the automated video-based system records velocity at the 10 m and 20 m marks respectively. Abbreviations: m.S-1, metres per second; s, seconds.

The differences in agreement can be explained by the nature of the strokes and the body segments that were tracked. Specifically, in backstroke and freestyle, the arms and legs alternate as the body rotates (rolls) about the longitudinal axis of the trunk (Gonjo et al., 2021). Conversely, in butterfly and breaststroke, a swimmer's body undulates in a wave-like motion using simultaneous arm and leg movements (Gonjo et al., 2021; Nicol et al., 2022; Strzała et al., 2017). Therefore, there is more vertical amplitude of the hips in butterfly and breaststroke and larger intra-cyclic velocity variations (Nicol et al., 2022; Strzała et al., 2017). It is likely that the tethered speedometer attached at the hip would have increased sensitivity to this undulatory movement compared to the automated video-based (head tracking) system, resulting in greater differences in velocity measurements between the two systems (T. M. Barbosa et al., 2015). This is evident in Figure 2c (breaststroke) which shows larger intra-cyclic velocity variations in the tethered speedometer velocity-time profile compared to the same profile from the automated video-based system.

Another factor contributing to the differences in agreement between the two systems relates to swimmers kicking the tether, which is a limitation of tethered speedometers (Alberty et al., 2005; Clément et al., 2021; Mooney, Corley, Godfrey, Quinlan, et al., 2016; Stamm et al., 2013). The interference can lead to measurement errors at the data points where the artefacts occur resulting in large differences in velocities compared to the automated video-based system. Figure 2d (freestyle) shows 'spikes' in the velocity-time profile from the tethered speedometer which are absent from the profile of the automated video-based (head tracking) system suggesting the swimmer kicked the tether. Given the Bland-Altman analysis calculates differences at every data point, the larger velocity

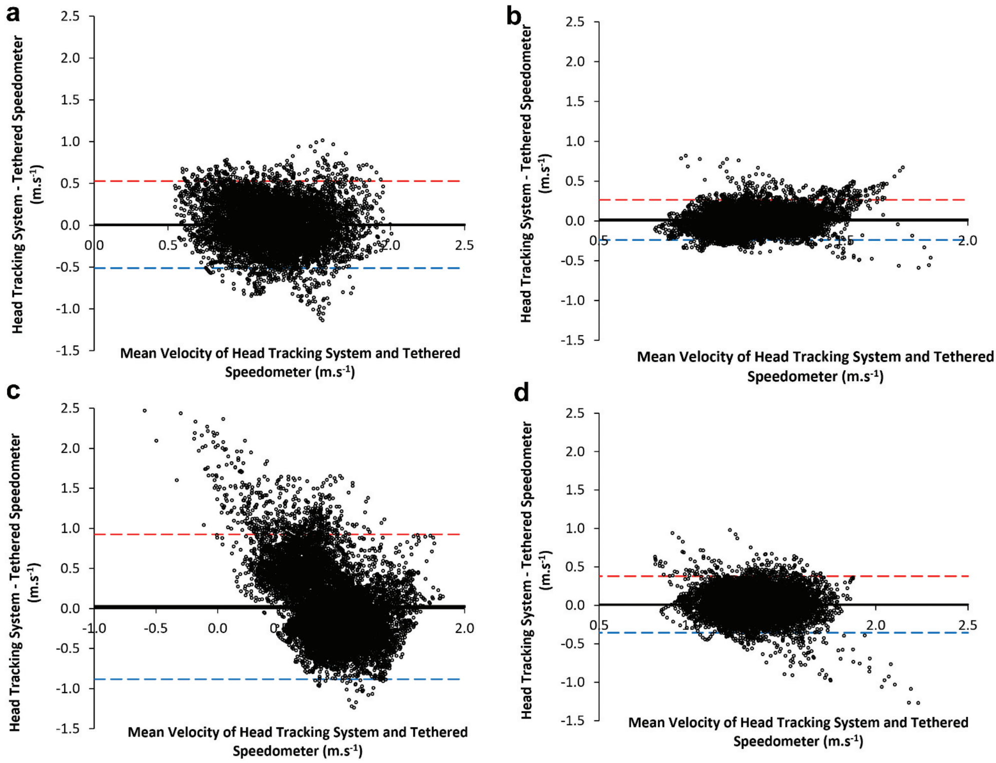

Figure 3. Bland-Altman plots comparing instantaneous swimming velocity from the automated video-based system to tethered speedometer measurements in the four swimming strokes (a: butterfly, b: backstroke, c: breaststroke, and d: freestyle). Solid horizontal line represents the bias (mean difference between systems) with dashed horizontal lines representing the upper and lower 95% limits of agreement. Abbreviation: $m.s^{-1}$, metres per second.

Table 2. Comparison (mean ± standard deviation) between the instantaneous swimming velocities from the automated video-based system and tethered speedometer for each swimming stroke.

		95% Limits of agreement		
Swimming stroke	Bias ($m.s^{-1}$)	Lower limit ($m.s^{-1}$)	Upper limit ($m.s^{-1}$)	RMSE ($m.s^{-1}$)
Butterfly	0.01 ± 0.01	−0.51 ± 0.11	0.53 ± 0.11	0.27 ± 0.06
Backstroke	0.01 ± 0.01	−0.24 ± 0.06	0.26 ± 0.07	0.13 ± 0.03
Breaststroke	0.02 ± 0.04	−0.88 ± 0.23	0.92 ± 0.29	0.46 ± 0.13
Freestyle	0.01 ± 0.01	−0.36 ± 0.07	0.38 ± 0.07	0.19 ± 0.03

Bias represents the difference between the automated video-based system and tethered speedometer instantaneous swimming velocity measurements. Positive values therefore represent an overestimation of the automated video-based system in comparison to the tethered speedometer.
Abbreviations: $m.s^{-1}$, metres per second; RMSE, Root Mean Square Error.

differences at these ‘spikes’ could explain the wider LOA for freestyle compared to backstroke where tether kicks were less evident. Stamm et al. (2013) also reported tether kicks in freestyle when they compared velocity measurements from an IMU and tethered speedometer, noting that the resultant velocity differences led to an increased number of data points lying outside the LOA. While there were no discernible tether kicks in butterfly and breaststroke in the present study, the artefact was reported by Clément et al. (2021) who compared an IMU with a tethered speedometer to measure instantaneous velocity in the four strokes. The researchers suggested that the greater range of body motion in butterfly and breaststroke increased the risk of swimmers kicking the tether and likely accounted for the wider LOA they observed in these two strokes compared to backstroke and freestyle (Clément et al., 2021).

To date, no study has compared instantaneous swimming velocity measurements from the automated video-based system to similar measures from an existing system (i.e., tethered speedometer, IMU, and manually digitised video-based system). Some studies (Clément et al., 2021; Dadashi et al., 2012; Stamm et al., 2013) have compared IMUs with tethered speedometers; however, with the exception of Clément et al. (2021), only freestyle has been assessed. Interestingly, when instantaneous swimming velocity is measured for freestyle at maximal intensity, the automated video-based system has less bias ($0.01\ m.s^{-1}$) and narrower LOA ($-0.36\ m.s^{-1}$, $0.38\ m.s^{-1}$) than what has been reported (Stamm et al., 2013) for an IMU (bias: $-0.03\ m.s^{-1}$, LOA: $-0.76\ m.s^{-1}$, $0.70\ m.s^{-1}$). However, the IMU estimated instantaneous swimming velocity over 125 m (Stamm et al., 2013) compared to just 25 m by the automated video-based system and a known limitation of IMUs is that velocity estimation can rapidly degrade over time (Magalhaes et al., 2015). Only one study (Clément et al., 2021) has compared an IMU with a tethered speedometer in all four strokes and similar findings to the present study were reported (i.e., stronger agreement for backstroke and freestyle compared to butterfly and breaststroke).

Study limitations

There are limitations of this study. First, instantaneous velocity measurements were compared from different tracking locations (i.e., hip versus head). Studies comparing methods to measure instantaneous swimming velocity typically use similar attachment sites (e.g., lower torso) (Clément et al., 2021; Dadashi et al., 2012; Stamm et al., 2013). However, due to the nature of the two systems in this study, this was not possible, and it was important to implement data collection procedures similar to those used in current practice. Second, the competition level of the participants was not representative of the practical context in which the automated video-based system is being used. The swimmers in this study were state level or higher, while the automated video-based system analyses performances at national (Australian) and international championships (Elipot et al., 2019). The skilfulness of the young swimmers in the more complex strokes of breaststroke and butterfly could have also influenced the lack of agreement between the two systems for these strokes. As such, the external and ecological validity of the findings could be questioned. Finally, this study examined the agreement of the systems across 10–20 m portion of a 25 m trial; however, it does not provide insight into if the differences between systems occur at specific times of a stroke cycle.

Conclusion

While this study showed that the automated video-based system and tethered speedometer are comparable for measuring instantaneous swimming velocity for freestyle and backstroke, there were greater differences between systems for breaststroke and butterfly. Despite the low bias values between systems for breaststroke and butterfly, the LOAs between systems for these two strokes were quite large. Therefore, alternating between the two systems may not be suitable for coaches, sports scientists, and swimmers who rely on accurate feedback of performance to monitor training programmes and develop race strategies. As a practical application, during race pace training swimmers aim to perform repeated intervals at a velocity comparable to their best performance in competition. If the competition performance instantaneous velocities (measured through the video-based system) are used to set training targets, which are then assessed through a tethered system, ill-informed decisions could be made due to the discrepancy between system readings. Repeated measures that under- or over-estimate velocity may lead to energy expenditure and physiological adaptations inconsistent with training goals. Given the differences between systems, if multiple systems are being used to assess a swimmer, it is recommended to examine change in instantaneous velocity instead of absolute measurements and combining information on instantaneous velocity with other parameters. For example, changes in velocity across a race (coupled with corresponding stroke rates) would be useful in assessing race strategy, pacing, and the effectiveness of training programmes. In training, when synced with underwater video, intra-cyclic velocity variations derived from instantaneous velocity can assess stroke efficiency, propulsive continuity, and energy cost. Alternatively, it is recommended that if two systems are to be used interchangeably, which may be the case between training and competition, establishing measurement difference parameters for individual swimmers, will be important.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Nathan Elsworthy http://orcid.org/0000-0002-5223-6803
Victoria Brackley http://orcid.org/0000-0003-2926-7385
Crystal O. Kean http://orcid.org/0000-0003-0135-7178

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