BJMB
Brazilian Journal of Motor Behavior

XV^th International Symposium on Biomechanics and Medicine in Swimming —Porto Alegre, Brazil

EXPLORATORY VALIDATION OF TEMPORAL AND EVENT-BASED METRICS FROM TRITON 2 UNIT IN SWIMMERS WITH AND WITHOUT DISABILITY

ADRIÁN FEBLES-CASTRO*[1] | ANTONIO RODRÍGUEZ-FERNÁNDEZ*[2,3] | JESÚS J. RUIZ-NAVARRO[1,4] | JAUME MARCÉ GIL[5] | RAÚL ARELLANO[1]

Adrián Febles-Castro and Antonio Rodríguez-Fernández contributed equally to this work
[1] Aquatics Lab, Department of Physical Education and Sports, Faculty of Sport Sciences, University of Granada, Granada, Spain; adrianfebles@ugr.es, r.arellano@ugr.es
[2] Biomechanical Engineering Lab (BIOMEC), Institute for Research and Innovation in Health (IRIS), Universitat Politècnica de Catalunya - BarcelonaTech (UPC), Barcelona, Spain; antonio.rodriguez.fernandez@upc.edu
[3] Institut de Recerca Sant Joan de Déu, Esplugues de Llobregat, Spain.; antonio.rodriguez.fernandez@upc.edu
[4] Human Performance and Sports Science Laboratory, Faculty of Sports Sciences, University of Murcia, Murcia, Spain; jjruiznavarro@um.es
[5] High Performance Sports Centre of Sant Cugat (CAR), Paralympic Swimming Team, Sant Cugat del Vallès, Barcelona, Spain; monjaus@hotmail.com

Correspondence to: Adrián Febles-Castro. Aquatics Lab, Department of Physical Education and Sports, Faculty of Sport Sciences, University of Granada, Granada, Spain. adrianfebles@ugr.es

ABSTRACT

BACKGROUND: Wearable inertial sensors are increasingly used to monitor swimming performance; however, evidence regarding their validity remains limited and inconsistent, particularly in Para swimmers, whose alterations in coordination, symmetry and propulsion may challenge head-mounted inertial event detection. This study aimed to provide a preliminary evaluation of the validity and agreement of the Triton 2 Unit system (triaxial accelerometer, gyroscope and magnetometer) against video-based analysis in swimmers with and without disabilities. **METHODS:** Four male and two female competitive swimmers (three without disabilities and three Paralympic swimmers) performed a structured training protocol under controlled conditions. Performance metrics derived from the head-worn inertial sensor were compared with a video-based reference. Variables analysed included lap time, mean stroke rate, number of strokes, underwater time, and turn time. Agreement and accuracy were assessed using median bias, interquartile range (IQR), median absolute percentage error (MdAPE), Lin's concordance correlation coefficient (ρ_c), and non-parametric 95% limits of agreement. **RESULTS:** In swimmers without disabilities, Triton showed high agreement for lap time (ρ_c = 0.968), stroke rate (ρ_c = 0.962), and number of strokes (ρ_c = 0.955), with low relative errors. Moderate agreement was observed for underwater time (ρ_c = 0.829), while turn time showed poor agreement (ρ_c = 0.228). In Para swimmers, agreement was generally lower and more variable, with wider limits of agreement across all variables. Lap time (ρ_c = 0.869) and stroke rate (ρ_c = 0.822) showed the highest consistency, whereas underwater time, number of strokes, and turn time showed reduced agreement. In one swimmer with severe impairment (S5), the device failed to correctly identify lap structure, leading to invalid outputs. **CONCLUSIONS:** Triton 2 Unit provides acceptable accuracy for selected metrics in swimmers without disabilities under ecological conditions. In Para swimmers, increased variability and occasional detection failures limit its applicability, particularly for event-based variables and severe impairments.

KEYWORDS: Swimming | Wearable Electronic Devices | Motion Analysis | Sports for People with Disabilities | Validation Study

INTRODUCTION

Monitoring training load and performance is a key to understand swimmers' responses to training stimuli and in designing training sessions, requiring accurate and practical tools to inform coaching decisions. Wearable inertial sensors have emerged as a practical alternative to video-based analysis, offering the potential for real-time feedback with reduced operational demands. Among these, head-worn devices, such as the Triton 2 Unit (©TritonWear Inc., Toronto, ON, Canada), use inertial measurement units (IMUs) to detect and quantify spatiotemporal variables during swimming[1].

Previous validation studies on TritonWear are scarce and report inconsistent findings[2–4]. Under controlled conditions, studies have shown acceptable accuracy for lap time, average speed, turn time, and selected stroke variables; however, substantial variability has been reported for underwater and breaststroke-related metrics, and reduced accuracy has been observed in short intervals and high-intensity efforts[2,3]. In contrast, when evaluated during longer and more ecologically valid training sessions, the device has shown inaccuracies in stroke count, average speed, distance, and stroke-type classification[4]. These discrepancies may be partly explained by methodological heterogeneity across studies, including differences in training protocols, validation procedures, and the selection of performance metrics[2,4]. In addition, existing evidence is based on small sample sizes, heterogeneous swimmer populations, and earlier versions of the TritonWear system, limiting the generalisability of findings and supporting the need for further validation[2–4]. Moreover, despite the growing adoption of wearable technologies in swimming, no validation studies to date have included Para

swimmers, restricting the applicability of current evidence to this population. This gap is especially relevant because Triton-derived metrics depend on head-motion patterns and event detection, which may be altered in Para swimmers with physical impairments. Therefore, lower agreement and greater variability were expected in Para swimmers.
In this context, the present study aims to provide a comprehensive evaluation of Triton 2 Unit by examining the full range of variables derived from the device in both swimmers with and without disabilities across a wide spectrum of conditions, including variations in speed, resistance, stroke type, set duration, pacing, and dives. Beyond performance accuracy, this work seeks to implement a rigorous validation framework that also addresses reliability and repeatability. Data collection is currently ongoing; therefore, this study focuses on a preliminary subset of six participants (three para-swimmers and three swimmers without disabilities). These preliminary results are intended not only to provide early insights into device performance but also to support the ongoing refinement of the data processing and analysis pipeline.

METHODS

Participants

Four male and two female competitive swimmers (22.2±4 years; 1.73±0.05 m height and 65.2±7.8 kg body mass) participated in this study, including three swimmers without disabilities competing at national level (550±26 World Aquatics Points) and three Paralympic swimmers competing at international level (Paralympic Games finalists; one multiple medallist). The impairments of Para swimmers were: unilateral limb deficiency below hip (sport class S9), unilateral limb deficiency below elbow (sport class S9), and spinal cord injury (SCI) T11 (sport class S5). All participants had extensive training experience and were actively engaged in regular swim training at the time of data collection. The study protocol was conducted in accordance with the principles of the Declaration of Helsinki (1975, reviewed in 2013) and was approved by the University of Granada Research Ethics Committee (reference number: 3256/CEIH/2023, 12 September 2023). Prior to participation, all participants received a verbal explanation of the study procedures and provided written informed consent.

Protocol

The accuracy of the Triton 2 unit (v1.3) was evaluated against video analysis, considered the gold standard. All swimmers performed the protocol described in Table 1, with adjustments based on pool length (swimmers without disabilities: 25 m pool; Para swimmers: 50 m pool). Additionally, for the lower sport-class swimmer, total volume was reduced (1900 to 1500 m) to match the overall session duration (Table 1). All participants were instructed to follow the prescribed protocol as consistently as possible, avoiding unnecessary or atypical movements, and to maintain a vertical position during rest periods in accordance with the manufacturer's recommendations.

Table 1. Experimental protocol performed by swimmers without disabilities (left) and Para swimmers (right).

Swimmers without disabilities	Para swimmers
25 m pool, total distance: 1750 m (70 laps)	50 m pool, total distance: 1900 m (38 laps)
- 600m warm-up (SWU[5])	
• 150 m (Normal – breathing in 5th stroke – Normal)	
• 2 x 100 m (25 m kick – 25 m increase stroke length)	
• 4 × 50 m (50 m drill – 50 m increasing speed – 2 × 50 m [25 m race pace / 25 m easy])	
• 50 m easy swim	
- 1 x 200 m IM (Zone 2)	
- 4 x 25 m IM order (sprint)	- 4 x 50 m IM order (decreasing speed)
- 3 x 50 m free (1 increasing speed, 1 decreasing speed, 1 easy)	- 4 x 50 m free (1 increasing speed, 1 decreasing speed, recovery, 1 200 m pace, 1 easy)
- 1 x 100 m IM (Zone 1)	
- 1 x 400 m (Zone 2)	
- 100 m easy swim	
- 4 × 25 m (15 m sprint from dive start)	- 4 x 50 m (15 m sprint from dive start)

Note. SWU, short warm-up; IM, individual medley.

Procedures

The Triton 2 unit (v1.3) was positioned under the swim cap on the swimmer's occipital protuberance, in accordance with the manufacturer's recommendations. The device integrates triaxial accelerometers, gyroscopes and magnetometer to derive spatiotemporal performance metrics. Video footage was recorded using two digital cameras (Sony FDR-AX53,

Sony Electronics Inc., Tokyo, Japan) at 25 Hz and positioned at an elevated lateral viewpoint, following established race analysis procedures[5]. Cameras were synchronised using a light flash prior to recording. Data were obtained through systematic event-based video analysis. Key events were defined a priori based on the Triton 2 Unit user manual and operationalised for manual identification[1]. Segmentation errors (sets, repetitions, and laps) were manually corrected before analysis to ensure valid comparisons. Two evaluators annotated events using in-house software. Time stamps were used to derive performance metrics. Additionally, wall contact events were identified using touchpads (ALGE-Timing GmbH, Austria), providing a visual signal upon contact.

Performance metrics were computed following Triton 2 Unit procedures. A total of five metrics were selected for this preliminary study. Additional device metrics are derived from these variables. Data analysis was performed using MATLAB (MATLAB R2025a, The MathWorks Inc., Natick, MA, USA).

The variables analysed were defined as follows: *Lap time* was defined as the time elapsed between two consecutive wall contacts. The *number of strokes* corresponded to the total strokes performed within each lap. *Mean stroke rate* was calculated as the average stroke rate excluding the first cycle; for freestyle and backstroke, the calculation started when the hand completing the second stroke re-entered the water, whereas for breaststroke and butterfly, it began after the second stroke and ended at the last complete stroke cycle. *Underwater time* was defined as the time from head water entry or wall contact until the swimmer's head broke the surface, with breakout identified when at least half of the swim cap became visible above the water. *Turn time* was defined as the time required to change direction, measured from head submersion in tumble turns or hand contact with the wall in open turns to foot contact with the wall.

Statistical analysis

Preliminary Shapiro-Wilk tests confirmed a non-normal distribution of error ($p < .05$), justifying a non-parametric approach. System accuracy and reliability were quantified using Median Bias, Interquartile Range (IQR), Median Absolute Percentage Error (MdAPE), and Lin's Concordance Correlation Coefficient (ρ_c). The ρ_c was reported with its 95% confidence interval (CI) and decomposed into precision (ρ) and accuracy (C_b). Agreement was assessed using Bland-Altman plots with 95% non-parametric limits of agreement (LoA). Data analysis was performed using R (v4.4.0). Statistical significance was set at $\alpha = .05$. One Para swimmer (sport class S5) was excluded due to discrepancies between video- and Triton-derived lap identification.

RESULTS

Table 2. Concurrent validity, agreement, and error metrics between Triton Unit 2 and video reference.

			Bias and Error			Agreement			Normality (p-value)
Group	Metric	N	Median [95% LoA, NP]	IQR	MdAPE (%)	ρ_c [95% CI]	Prec. (ρ)	Acc. (C_b)	
Swimmers without disability	Lap time (s)	210	0.085 [-1.580,0.828]	.455	1.221	0.968 [0.959,0.976]	.969	.999	<.001
	Stroke rate (cyc·min^{-1})	192	-0.531 [-5.760,3.094]	1.446	2.571	0.962 [0.950,0.971]	.967	.995	<.001
	Underwater time (s)	210	-0.040 [-1.444,0.713]	.555	10.980	0.829 [0.783,0.867]	.843	.984	<.001
	Number of strokes	192	0.000 [-2.000,1.000]	.000	.000	0.955 [0.941,0.966]	.957	.998	<.001
	Turn time (s)	141	0.230 [-0.230,0.695]	.390	21.905	0.228 [0.134,0.317]	.401	.567	.038
Para swimmers	Lap time (s)	75	-0.160 [-13.484,4.559]	2.490	2.796	0.869 [0.800,0.915]	.871	.998	<.001
	Stroke rate (cyc·min^{-1})	70	0.744 [-4.642,2.137]	1.780	3.762	0.822 [0.730,0.885]	.825	.996	<.001
	Underwater time (s)	75	-0.440 [-1.949,1.526]	1.190	25.000	0.553 [0.397,0.679]	.620	.893	.174
	Number of strokes	71	0.000 [-15.750,3.000]	3.000	2.564	0.643 [0.504,0.749]	.706	.910	<.001
	Turn time (s)	27	0.160 [-0.874,0.576]	.200	16.000	0.318 [0.092,0.513]	.492	.646	<.001

Note. LoA, limits of agreement; NP, non-parametric; IQR, interquartile range; MdAPE, median absolute percentage error; ρ_c, concordance correlation coefficient; CI, confidence interval; Prec., precision; Acc., accuracy; cyc, cycles.

The concurrent validity and agreement between the Triton 2 Unit and the Video reference varied significantly across the different metrics and swimming groups (Table 3). Tests of normality indicated systematic deviations from Gaussian distributions (most $p < .05$), supporting the use of non-parametric summaries and agreement metrics.

Swimmers without disability

High agreement was observed for *lap time*, *stroke rate*, and *number of strokes* ($\rho_c \geq .955$; MdAPE ≤ 2.6%), indicating strong validity for cyclic metrics. In contrast, *underwater time* showed moderate agreement ($\rho_c = .829$; MdAPE = 11%), while *turn time* demonstrated poor agreement ($\rho_c = .228$; MdAPE = 22%), reflecting limitations in event detection.

Para swimmers

In Para swimmers, *lap time* and *stroke rate* ($\rho_c = .822, .869$; MdAPE = 3.8%, 2.8%, respectively) showed the highest agreement, although with wider limits of agreement. In contrast, *number of strokes* ($\rho_c = .643$), *underwater time* ($\rho_c = .553$; MdAPE = 25%), and *turn time* ($\rho_c = .318$) demonstrated reduced agreement. Additionally, lap detection errors were observed in a swimmer with severe impairment, leading to invalid metrics and participant exclusion from the analysis.

DISCUSSION

Swimmers without disability

In swimmers without disability, the Triton system demonstrated good agreement with the video-based reference across most variables, particularly in *lap time*, *stroke rate*, *underwater time*, and *number of strokes*. Near-zero median biases and relatively narrow limits of agreement suggest acceptable accuracy under controlled conditions. Bland-Altman plots showed consistent clustering despite variability in swimming velocity and between-swimmer differences, indicating stable performance under heterogeneous conditions (Figure 1).

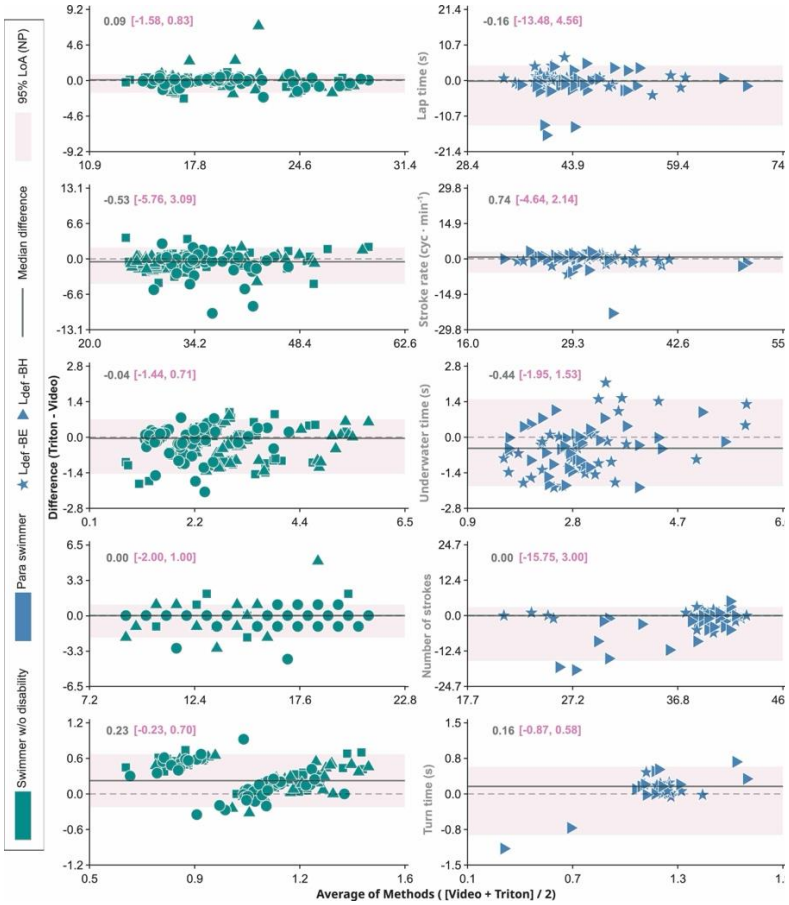


Figure 1. Bland-Altman plots showing bias and limits of agreement between Triton 2 Unit and video-derived measurements by group. Swimmers without disability, left side; Para swimmers, right side. L_{def}-BE, limb deficiency below elbow; L_{def}-BH, limb deficiency below hip; LoA, limits of agreement; NP, non-parametric.

The higher consistency in *lap time*, *stroke rate*, and *number of strokes* likely reflects their cyclic and temporally derived nature. In contrast, variables such as *underwater time* and *turn time* depend on the accurate identification of discrete events, increasing variability (Figure 2). This may explain the wider dispersion observed in *underwater time* despite near-zero bias, as well as the consistent positive bias in *turn time*, likely due to delays in event detection. This interpretation is consistent with previous findings showing reduced accuracy of IMU-based systems during short, high- velocity efforts and phases

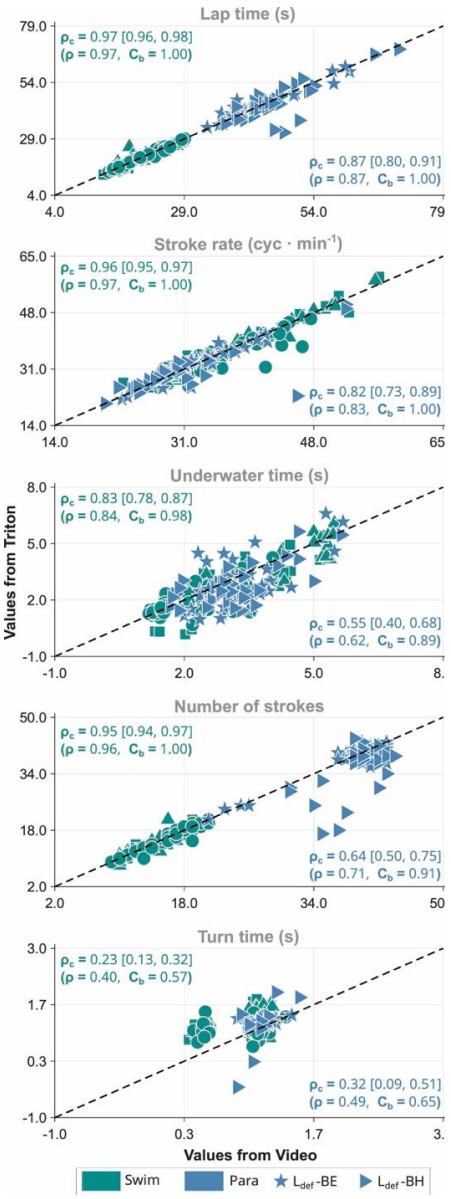


Figure 2. Scatter plots illustrating concordance between Triton Unit 2 and video reference for performance variables. **Note.** (ρ), precision; (C_b), accuracy; cyc, cycles; L_{def}-BE, limb deficiency below elbow; L_{def}-BH, limb deficiency below hip.

requiring precise event detection[3]. Furthermore, two distinct clusters were observed in turn time, likely reflecting different turn types. Combining turn types may introduce variability and affect agreement estimates; therefore, future studies should consider clustering data according to turn type to improve measurement accuracy and interpretability.

Para swimmers

In Para swimmers, wider LoA were observed across all variables despite relatively small median biases, indicating increased random error and reduced reliability (Figure 1). This effect was particularly evident in *lap time* and *number of strokes*, where large LoA indicate reduced consistency under variable movement conditions. This is in line with previous work questioning the accuracy of wearable sensors during more ecologically valid conditions, particularly for complex performance metrics[4]. *Stroke rate* showed comparatively narrower limits of agreement, and ρ_c values indicated that *lap time* (.869) and *stroke rate* (.822) were the most reliable metrics. The cyclical nature of stroke execution may explain this robustness, consistent with previous findings on temporally derived variables[3].

In contrast, reduced agreement in variables such as *number of strokes*, *underwater time*, and *turn time* likely reflects increased within-group variability in movement execution. Altered coordination, symmetry, and propulsion strategies may affect the inertial signals captured by the Triton 2 Unit, as event detection relies on acceleration and angular velocity patterns recorded at the device location, particularly at lower velocities or movement amplitudes, consistent with increased error previously reported in underwater phases and event-dependent variables[2]. Qualitative observations confirmed errors in repetition detection and lap identification, including missed repetitions and misclassification in more severe impairments.

Several outliers were identified (Figure 2), suggesting an influence of impairment-specific movement patterns. These data were retained to preserve ecological validity. Additional inaccuracies were observed in breaststroke stroke detection, likely due to modified coordination strategies that may not be captured by the device algorithms, reducing accuracy in stroke count despite the presence of a Para swimming mode. This may relate to reduced acceleration magnitudes and altered head kinematics affecting event detection. More broadly, difficulties were observed in identifying sets and repetitions during typical training conditions, particularly in repeated structures. These errors occasionally resulted in miscounting of pool lengths, reflecting the sensitivity of event-detection algorithms to heterogeneous movement patterns[4]. These factors should be considered to avoid misinterpretation of performance metrics.

Limitations

This study presents several limitations that should be considered when interpreting the findings. First, data collection was performed in pools of different lengths (25 m and 50 m); shorter pool lengths provided a greater number of repeated events, such as turns, whereas longer pool conditions resulted in fewer repetitions but longer continuous swimming segments, potentially affecting the distribution and interpretation of the variables. Second, the Bland-Altman analysis was conducted using repeated measures from the same swimmers, which violates the assumption of independence.

Although appropriate statistical approaches were applied to reduce this effect, some degree of bias in the estimates cannot be excluded. Third, video-based measurements in the 50 m pool were subject to reduced precision due to the increased camera-to-swimmer distance and the absence of a wall-mounted reference system to accurately determine wall contact, which may have affected the accuracy of the criterion measure. This study should be considered a preliminary investigation aimed at identifying methodological constraints and sources of error to inform future, larger-scale validation studies.

Practical Applications

Triton appears to offer acceptable accuracy for monitoring *lap time*, *stroke rate*, and *stroke count*, particularly in structured training conditions. However, measurement variability increases in more complex scenarios, especially for event-based variables, and wider limits of agreement should be expected. Variables such as *turn time* and underwater phases should be interpreted with caution due to greater variability associated with event-detection limitations. In swimmers with severe impairments, the device may fail to correctly detect lap structure, limiting its suitability for performance monitoring. Additionally, inaccuracies in the classification of sets, repetitions, and laps may occur, particularly in sessions with repeated structures, and may require manual verification before analysis.

CONCLUSION

From an applied perspective, in swimmers without disability, these findings suggest that metrics derived from continuous cyclical patterns may be more robust than those relying on discrete event detection. Accordingly, *lap time* and *stroke rate* appear suitable for monitoring, whereas greater caution may be required when interpreting variables linked to turns and underwater phases, particularly under more complex or ecologically valid training conditions.

In contrast, in Para swimmers, errors were not consistent across metrics and tended to increase in magnitude and variability, especially for event-based variables. The Triton system may therefore be suitable for selected metrics, such as *stroke rate*, under controlled conditions; however, its use for comprehensive performance analysis remains limited. Notably, in this preliminary analysis, the device did not provide valid lap-based temporal data in a swimmer with severe impairment, highlighting the potential influence of impairment severity on measurement accuracy. Although this observation is based on a single case and should be interpreted with caution, it suggests that the current para-swimmer mode may not fully capture the diversity of movement patterns present in this population, reinforcing the need for further refinement of detection algorithms in Para swimming contexts.

REFERENCES

1. User Manual, TritonWear. Triton 2 unit. Published online October 2019.
2. Butterfield J. Concurrent validity and test-retest reliability of an elite tracking system to assess.
3. Pla R, Ledanois T, Simbana ED, et al. Spatial-temporal variables for swimming coaches: A comparison study between video and TritonWear sensor. *Int J Sports Sci Coach*. 2021;16(6):1271-1280. doi:10.1177/17479541211013755
4. Shell SJ, Clark B, Broatch JR, Slattery K, Halson SL, Coutts AJ. Is a Head-Worn Inertial Sensor a Valid Tool to Monitor Swimming? *Int J Sports Physiol Perform*. 2021;16(12):1901-1904. doi:10.1123/ijspp.2020-0887
5. Neiva HP, Marques MC, Barbosa TM, et al. The Effects of Different Warm-up Volumes on the 100-m Swimming Performance: A Randomized Crossover Study. *J Strength Cond Res*. 2015;29(11):3026-3036. doi:10.1519/JSC.0000000000001141
6. Arellano R, Ruiz-Navarro JJ, Barbosa TM, et al. Are the 50 m Race Segments Changed From Heats to Finals at the 2021 European Swimming Championships? *Front Physiol*. 2022;13. doi:10.3389/fphys.2022.797367

ACKNOWLEDGEMENT and FUNDING

The authors would like to sincerely thank all swimmers and coaches involved in this study for their valuable time, commitment, and collaboration. Their contribution was fundamental to the successful completion of this research. This research was partially supported by the ALECTOR2024 grant from the Universitat Politècnica de Catalunya – BarcelonaTech (UPC) and by the Grant PID2022-142147NB-I00 (SWIM III) funded by MICIU/AEI/10.13039/501100011033/ and by ERDF, EU. AFC holds an FPI fellowship, which is funded through the aforementioned grant.