# Assessment of feedback devices for performance monitoring in master's swimmers

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## ABSTRACT

In recent years, new portable performance monitoring devices have appeared in swimming. The study aims to establish the current validity of the *FORM Goggles*, *Finis Stopwatch*, and the *Garmin Swim 2 Watch*, for the partial and total times and stroke count (experiment 1; n = 17) and to compare the effect of the devices considered as valid in monitoring the pace of master swimmers (experiment 2; n =10). The *FORM Goggles* and the *Finis Stopwatch* showed good level of agreement and accuracy (*Bland Altman plots* showed homoscedasticity and in most cases Lin's concordance correlation coefficient were > 0.95, and the error magnitude < 0.2 seconds). These systems allow better pace control compared to *Garmin Swim 2*, with a difference between target and actual time below 1.5 %. However, the results showed that the concurrent feedback provided by *FORM Smart Swim Goggles* could offer greater advantages than the traditional feedback provided via the *Finis Stopwatch* at the end of each series, as swimmers were closer to the target time ($p < 0.05$). In conclusion both the *FORM Goggles* and the *Finis Stopwatch*, showed a good validity and could serve for performance monitoring in swimming, allowing the *Form Goggles* better pace control.



Keywords: Technology; physical preparation; training control; individualization; swimming.

## 1. Introduction

Over the past two decades, the number and diversity of portable electronic devices equipped with multiple sensors and performance monitoring applications is constantly growing and evolving (Cusano et al., 2019; Peake et al., 2018). These new technologies have produced a transformation in all areas of society, including sports training, resulting in the modification of some evaluation procedures to maximize the performance of athletes (Rajšp & Fister, 2020). These tools make it possible to replace qualitative procedures (subjective and error-prone) with quantitative data collection procedures, both in team and individual sports (Lutz et al., 2020).

When choosing new technology, it is important to consider whether it produces desirable results, whether it has been developed according to real-world needs and whether its effectiveness has been proven in different environments (e.g., validated in independent research) (Peake et al., 2018). In fact, one of the problems related to the high proliferation of electronic devices and performance analysis apps is the little information that exists regarding their validity, i.e., that they are able to measure what they intend to measure (Scott et al., 2016). This is essential since the data obtained is used to prescribe, monitor, or alter training regimens (Peake et al., 2018; Scott et al., 2016).

More specifically in swimming, the use of technologies is widely recognized as a key tool for improving competitive performance (Magalhaes & De, 2015; O'Donoghue, 2006; Pansiot et al., 2010). However, research in this area has not been able to advance at the same level as in other disciplines due to the multiple constraints of the research environment (e.g., use of tools underwater, humidity conditions, image distortion…)

(Delgado-Gonzalo et al., 2016). Traditionally, coaches and researchers have used video analysis to acquire reliable quantitative and qualitative data on performance (O'Donoghue, 2006). However, this approach is computationally intensive, thus introducing a delay in the provision of quantitative information to athletes (Magalhaes & De, 2015; Pansiot et al., 2010). Today, thanks to advances in kinematic tracking, swimmers can also monitor their own activity using wearable technologies such as inertial and magnetic sensors, which have high performance and low cost (Magalhaes & De, 2015). In this sense, technology is becoming increasingly personalized towards the user, even offering the possibility of providing real-time feedback on the quality of the activity (Peake et al., 2018).

Feedback in sport science can be defined as the return of information about the outcome of a skill action (Szczepan et al., 2018). The literature identifies two types of feedback: i) intrinsic feedback, which is the sensory information derived from proprioceptive and exteroceptive receptors that allow the regulation of movement, as well as a better structuration of the motor programs by the "feelings" associated with movement (Szczepan et al., 2018); ii) extrinsic feedback, which consists of any information (e.g. verbal or visual) about the performance of a motor skill that is supplied by a source external to the performer and that supplements or adds to the performer's sensory feedback (Szczepan et al., 2018). The timing of corrective feedback has also effects on performance (Silverman et al., 1998). In this sense, feedback can be concurrent or real-time, immediate or delayed if provided during, just after, or following a period of time (Zaton & Szczepan, 2012).

In general, the control of swimmers' pace and athletic performance is affected by the type of feedback provided, as well as the amount and frequency of administration (Pérez et al., 2009). Concurrent or real-time feedback allows learners to correct wrong initial decisions while performing the action (Szczepan et al., 2018) and is an effective way to maintain the specific swimming speed and intensity according to the type of training (Szczepan et al., 2016). This is especially important when preparing a training-set for a middle-distance race (e.g., 200 or 400 m front-crawl), where it is desirable to maintain a target pace, close to that of the competition, over the repetitions established for that particular workout (e.g., 10 × 100m) (Cuenca-Fernández et al., 2021), thus, making necessary to use individualized feedback systems that provide a real-time value of the execution (McGibbon et al., 2018). In this sense, it is essential that these instruments are easy to wear so that they do not interfere with the swimmer's performance (Bächlin & Tröster, 2012).

Traditionally, the coach has provided information on swim pace using a manual stopwatch, such as the *Finis® Stopwatch*, specifically for swim training and with a function to estimate stroke rate. By using the stopwatch, the coach usually gives feedback to the swimmer at the end of each series or partial, attempting to maintain or modify the swim pace. Nowadays, wearable sensors embedded in swimming goggles or smartwatches could be interesting alternatives to provide real-time feedback. For example, the Canadian brand FORM® has designed the *Smart Swim Goggles* (*FORM Goggles*), which include a transparent display that offers real-time feedback on time, distance, or pace; a feature not available with other devices. Some commercially available swimming watches have also gained relevance. For instance, the *Garmin Swim® 2 Watch* allows to track the distance covered, the number of strokes per lap, and the heart rate (via a wrist plethysmographic sensor or a chest-strap transmitter) at the end of each series or partial.

Therefore, this study had two objectives: i) to study the validity of the *Finis Manual Stopwatch*, the *FORM Goggles*, and the *Garmin Swim 2 Watch* in a 200 m front-crawl swimming test (experiment 1), and; ii) to observe the effects of swimming feedback devices considered to be valid on pace control in a 10 × 100 m front-crawl (experiment 2).

## 2. Materials and methods

### *2.1. Experimental approach to the problem*

For the first aim of the study, swimmers completed a 200 m front-crawl test and the validity of three different instruments for providing feedback (*FORM Goggles, Garmin Swim 2 Watch* and *Finis Stopwatch*) was compared with an accurate photogrammetric system. For the second aim (i.e., to compare the swimming feedback devices considered valid) a sub-sample of swimmers was counterbalanced and randomly assigned into groups that performed each test (10 × 100 m) on different days, separated by at least 48 hours.

(Please insert Figure 1 near here)

### *2.2. Sample*

All participating swimmers were provided with detailed information on protocols, execution days, characteristics, and instructions to follow for testing. Likewise, all of them were offered the possibility of participating in the first aim of the study without the binding commitment of having to intervene in the second. To accomplish the first objective of the study, 17 volunteer swimmers were selected (9 men and 8 women; 25.3 ± 5.7 years old; height: 171.4 ± 9.4 cm; body mass: 63.8 ± 12.2 kg). All of them were competitive master swimmers who participated in regulated training 3-5 days/week, with an average of 7 ± 3.7 training hours/week. For the second aim, 10 of these swimmers also participated on a voluntary basis (25.1 ± 4.3 years old; 171.3 ± 10.3 cm in height; 65.4 ± 12.9 kg in weight). The procedure was explained to the swimmers, who signed an informed consent form prior to participating in the study. All interventions were conducted in accordance with the Declaration of Helsinki for Human Studies, and the research protocol was approved by the University Ethics Committee (code XXXXX).

### ***2.3. Materials***

*FORM Goggles* (FORM Athletica Inc, Vancouver, Canada) has a transparent display on one of the lenses that allow real-time or concurrent feedback of certain performance parameters such as total time, lap time, swim distance, pace, stroke rate, number of strokes, stroke type, distance per stroke and calories. All data is saved in the *FORM Swim App* and can be downloaded later. The *Garmin Swim 2 Watch* (Garmin International Inc, Olathe, Kansas, USA) is a smartwatch created specifically for swimming that collects parameters such as total-time, lap-time, swimming distance, pace, stroke count, type of stroke, and calories. All data can be accessed after the workout is complete in the *Garmin Connect app*. The *Finis Stopwatch* (Finis Inc, Livermore, California, USA) has three buttons (start/stop, recall, lap/split/reset), and includes a display with the partial and total time. A photogrammetric system for swimming performance analysis (named *ASPA*, an acronym for Automatic Swimming Performance Analysis) was used as a reference. This system consists of 8 synchronized cameras (Basler Aviator, 83.33 Hz, 1080 x 1080 pixels, 1Gb Ethernet connection to a central computer), strategically placed on the roof to collect the entire pool area. The *ASPA system* allowed obtaining and reporting data of total and partial lap-times (*see Supplemental online material*) and has proven to be valid (Arellano et al., 2018; Arellano et al., 2018).

### *2.4. Procedure*

The tests were carried out in a 25-m pool, with water and air temperature (27.3 and 29.4 degrees, respectively) and humidity control (52%). Participants were instructed to abstain from eating for four hours preceding the experiments, to refrain from physical exercise on the test day, and from consuming alcohol or caffeine for the previous 48 hours. Prior to each test, participants conducted an in-water warm-up, following recommendations from the literature (Cuenca-Fernández et al., 2022; Neiva et al., 2014). It consisted of 1,000 m at moderate intensity alternating styles and included technique and leg exercises and changes of pace. Between the warm-up and the test, a passive rest of 5 min was included. On the first day, height and body mass were taken during this time.

To assess devices validity, swimmers completed a 200 m front-crawl test at maximum speed, equipped with *FORM Goggles* and the *Garmin Swim 2 Watch*. In addition, total-time and 8 × 25 m-partial times were collected with a *Finis Stopwatch* and the entire race was recorded with the *ASPA system*. On different days (separated by at least 48 hours) and counterbalanced, a sub-sample of swimmers performed 10 × 100 m training sets at a specific pace according to different extrinsic feedback devices, depending on whether the instruments were valid. Specifically, i) the *Finis Stopwatch* and *Garmin Swim 2 Watch* would provide swimmers with immediate verbal feedback every 100 m partial; ii) *FORM Goggles* would provide concurrent feedback. Time performances were recorded on each rep and participants were asked to rate their effort through the Borg Rating of Perceived Exertion (RPE) scale (Borg, 1999). The RPE scale was introduced because perceived exertion is considered one of the main factors related to swimming pace (Baldassarre et al., 2021) and could be affected by the feedback received (Skorski & Abbiss, 2017).

Individual training paces for the 10 × 100 m sets were determined using the 200 m time and Pyne's formulas (Pyne, 1999). Specifically, the pace was calculated by dividing the 200 m test time by two and adding 4-7 seconds. This corresponds to a high-performance endurance pace, in which the swimmers worked at near maximum intensity (Pyne, 1999). An individual work-recovery ratio of 1.5:1 was established based on this target time (e.g., a swimmer with a target time of 60 seconds could allow 40 seconds of rest between repetitions). During the recovery time, the swimmer was given the time of the last partial time recorded with the *Finis Stopwatch* and his RPE was recorded.

### *2.5. Statistical analysis*

All statistical procedures were performed using OriginLab and Microsoft Excel. The significance was set at $p < 0.05$. Descriptive statistics were expressed as mean ± standard deviation (SD). The normality of the distribution was confirmed with the Shapiro-Wilk test and homoscedasticity was confirmed with the Levene test. For the first aim of the study, the data obtained by the *ASPA system* were compared with those obtained by the feedback devices (*FORM Goggles*, *Finis Stopwatch*, *Garmin Swim 2 Watch*) using an *ad-hoc Excel spreadsheets*. *Bland-Altman plots* with regression line trends were used to observe the magnitude-dependent bias and detect extreme values. The magnitude of the error was assessed with the Mean Absolute Error (MAE) and with the Mean Percentual Absolute Error (MAPE) dividing the MAE by the mean. The linear relationship and the level of agreement was evaluated with the Lin concordance correlation coefficient (Lin CCC), where a high coefficient indicated a low systematic error difference between measures. To evaluate the strength of agreement of the correlation coefficients, the following scale was used: less than 0.90 poor, 0.90-0.95 moderate, 0.95–0.99 substantial and greater than 0.99 almost perfect (McBride, 2005). To consider the swimming feedback device as valid the magnitude of the error (MAE) for the 25 m-partial times had to be less than the Mean Smallest Meanwhile Change (MSWC) calculated based on the *ASPA* system, using equation 1 (Crowcroft et al., 2017; Hopkins et al., 1999).

$$MSWC = \frac{\sum_{i=1}^{n} 0.3 \times \text{ within swimmer SD of each 25 m partial times}}{number\ of\ swimmers} \ (1);$$

To compare the effect of the feedback device on speed control, it was first calculated the percentual time to target time (PTT) with equation 2. This variable was computed for each type of feedback device, for each 100 m partial and for each swimmer. A positive value for this score denotes that the swimmer performed the repetition in less time than the target time and vice versa. For descriptive purposes, the mean PTT of each 100 m-partial time was calculated for each feedback device (considering the values of all 10 swimmers). To compare the PTT between the feedback devices at the end of each repetition, a general linear model was used including as independent variables the feedback device used, the swimmer and the partial (categorical variables) and as a dependent variable the PTT. The swimmer and the repetition were included in the model to analyze the differences between the different types of feedback devices controlling for both variables, considering that can influence the PTT.

$$Percentual\ time\ to\ target\ time\ (PTT) = \frac{Target\ time\ (s) - Time\ obtained\ (s)}{Target\ time\ (s)} \times 100 \ (2)$$

## 3. Results

***Experiment 1: Validity assessment of the three swimming feedback devices in the 200 m test***

The total time was about 150 seconds, and the 25 m-partial times were between 15 and 20 seconds (Table 1). The total number of strokes were of 155.17 ± 18.81, 158.58 ± 22.38 or 157.35 ± 20.69 when determined with the *FORM Goggles*, *Garmin Swim 2 Watch* or *ASPA system* respectively.

(Please insert Table 1 near here)

The Bland-Altman plots for the 25-m partial times and for the 25-m partial number of strokes showed homoscedasticity in the distribution of the data, indicating homogeneous variance as the true mean increases (Figure 2). This is confirmed by the R-values of the least squares lines of the error distribution, which are less than 0.04 in all cases. The largest errors (for both times and number of strokes) were found on the *Garmin Swim 2 Watch* and were even greater than 4 seconds and 5 strokes in a few cases (Figure 2).

(Please insert Figure 2 near here)

The MSWC for the 25 m. partial times was of 0.38 seconds. The *FORM Goggles* and the *Finis Stopwatch* showed a substantial correlation (Lin CCC = 0.97 in both cases) and an error magnitude with respect to the reference system less than the MSWC in all cases except one (Table 2). In contrast, the *Garmin Swim 2* Watch presented a poor level of agreement (Lin CCC = 0.71) and an error magnitude greater than one second, exceeding the MSWC (Table 2). Considering this result, the *Garmin Swim 2 Watch* was not considered a valid pace control device and was discarded for experiment 2. For total time, the level of agreement was substantially high for the *FORM Goggles*, the *Garmin Swim 2 Watch* and the *Finis Stopwatch* (Lin CCC was of 0.92, 0.99 and 0.99 respectively). The MAE was below one second for the *FORM Goggles* and the *Finis Stopwatch* and above 4 seconds in the *Garmin Swim 2 Watch* (Table 2). For the variable number of strokes by 25-m partials, the level of agreement was moderate for the *FORM Goggles* (Lin CCC = 0.88) and low for the *Garmin Swim 2 Watch* (Lin CCC = 0.52). The MAE was of 0.99 strokes and 2.33 strokes respectively. When the entire test was evaluated the level of agreement of the variable number of strokes for the *FORM Goggles* and the *Garmin Swim 2 Watch* was moderate (Lin CCC was of 0.94 and 0.93) and the MAE was of 6.00 and 8.30 strokes.

(Please insert Table 2 near here)

***Experiment 2: assessment of the swimming feedback device for pace control***

As mentioned above, for this experiment only the feedback provided with the *Finis Stopwatch* (after each partial) and the *FORM Goggles* feedback (real-time feedback) were considered, as the *Garmin Swim 2 Watch* have an error magnitude above the MSWC and subsequently was discarded. Relative to the RPE at the values with both devices were quite similar (RPE with the *FORM Goggles* was of 5.1 ± 2.1 and with the *Finis Stopwatch* it was of 5.5 ± 1.5).

The time to target times were of 0.63 ± 1.48 seconds. PTTs were mostly positive (in approximately the 70% of partials) with swimmers achieving faster times than the preset target time and in the first repetition it seems that the PPT was higher than in the later repetitions, regardless of the type of device (Figure 3).

(Please insert Figure 3 near here)

Regarding the study of the different types of feedback in the 10 × 100 m test, the general linear model revealed significative differences in the PTT between the two systems ($p < 0.05$; Table 3), the *FORM Goggles* showing a lower PPT than the *Finis Stopwatch* (Figure 3). There were also significant differences between swimmers and between repetitions (considered as control variables in the model).

(Please insert Table 3 near here)

## 4. Discussion

The first objective of this study was to evaluate the validity of the instruments: *FORM Goggles*, *Finis Stopwatch* and the *Garmin Swim 2 Watch*, using as a reference the data provided by the *ASPA system* for the analysis of swimming competition. In general, the total and partial times recorded by the three systems were similar (Table 1). Specifically, our results showed that, for the total time of a 200 m swimming event, all instruments had a substantial agreement with respect to the *ASPA system*. In the case of the partial times only the *FORM Goggles* and the *Finis Stopwatch* showed a good level of agreement and good accuracy (Figure 2; Table 2). Although the *Garmin Swim 2 Watch* was the one that presented the lower concordance of the three systems with a higher average absolute error. Relative to the second aim of the study considering the MSWC, only the *FORM Goggles* and the *Finis Stopwatch* were selected. Both showed a

PPT below a 2.5% (Figure 3), but the *FORM Goggles* allow for better control of the swimming pace ($p < 0.05$; Table 3).

***Experiment 1: Validity assessment of the three swimming feedback devices in the 200 m test***

In the case of the variable 25 m-partial times, some differences between instruments were observed. The *Lin CCC* of the *Garmin Swim 2 Watch* resulted in a value below 0.90. In fact, as can be seen in the Bland-Altman graphs (Figure 2) the point dispersion cloud was greater in the *Garmin Swim 2 Watch*, which indicated greater differences with respect to the reference system. Specifically, it can be observed how this instrument had a lower validity in the first partial of 25 m (MAPE was of 5.38%, 14.1% and 1.63% respectively higher than in the rest of partials) (Table 2). At the last partial the MAPE was also higher than in the rest of partials (Table 2). These results were in line with previous results (Mooney et al., 2017), where a significant difference was reported with the *Garmin Swim 2 Watch* for lap times made at the beginning and end of a test. A possible explanation for this could be that this instrument had problems detecting both the start time of the swim and the end of the test due to the algorithm used (probably based on the gyroscope). Depending on the movement that occurs before the wall thrust, can cause the sensor to start recording a new turn before it has actually started (Mooney et al., 2017).

In relation to the variable total number of strokes, the results showed a moderate correlation agreement for both instruments (*FORM Goggles* and *Garmin Swim 2 Watch*) compared to the *ASPA system*. The *Garmin Swim 2 Watch* showed a concordance of 0.93 and an average absolute error of 8.30 strokes. Similar data were obtained in another study (Pan et al., 2016), concluding that the average precision of number of strokes measured with the *Garmin Swim 2 Watch* in front-crawl was around 85.7%. The *FORM Goggles* showed an average absolute error of 6 strokes, slightly lower than the *Garmin Swim 2 Watch*. On the other hand, for the variable 25 m-partial number of strokes, the concordance of the *FORM Goggles* was moderate, while that obtained by the *Garmin Swim 2 Watch* was poor. The *Garmin Swim 2 Watch* stroke detection in a partial is probably based on the gyroscope, specifically in the cessation of the arm cycle during turns. In many cases the swimmers continue to move their arms during this action, and this would cause it to fail in the stroke count in a certain part of the test.

***Experiment 2: assessment of the swimming feedback device for pace control***

The second objective of this study was to determine the effect of the feedback provided by the devices considered as valid (based on the MSWC, computed in the first experiment) on the control of the swimming pace. The *Garmin Swim 2 Watch* was discarded based on the results of the experiment one as it showed an error magnitude higher than the MSWC. Therefore, the effects on the swimming pace of the feedback provided by the *Form Goggles* (concurrent feedback) and the *Finis stopwatch* (verbal feedback every 100 m partial) were analyzed. The results obtained showed that the use of the *FORM Goggles* (providing concurrent feedback) improved the control of the swimming pace compared with the usage of the *Finis Stopwatch* (which provide immediate verbal feedback every 100 m partial, as traditionally done by coaches). Therefore, the use of this type of concurrent feedback based on the *FORM Goggles* would be effective in controlling the speed of swimming (Altavilla et al., 2018; Pérez et al., 2009; Szczepan et al., 2016; Zaton & Szczepan, 2012).

Fewer differences than expected were found in the condition of verbal extrinsic feedback, considering previous data (Altavilla et al., 2018). Those authors registered times 2.87 seconds faster than the target time in a real time voice feedback modality and 4.73 s in a real time visual feedback modality, and in the present study the mean value was less than one second. The differences could be due to the differences between the swimmers in the two samples, the characteristic of the task or the type of feedback provided. Besides, only master swimmers were included in the present investigation. Hence, it is likely that swimmers with extensive training experience are better able to control swimming pace without any extrinsic feedback as in a real competition (McGibbon et al., 2018). If they are also given extrinsic feedback at the end of each partial, they will be better able to adjust the pace between them.

In the present study, in both feedback situations the swimmers swam below the target time (at a higher speed than the required speed). The effect of a workout performed on at higher intensity than initially anticipated, can lead to lower levels of performance, and altered physiological and psychological states (Almási et al., 2021; Cuenca-Fernández et al., 2021). Therefore, the concurrent feedback provided by the *FORM Goggles* could prevent this type of situation, by training at an intensity close to competitive pace. In this sense, and despite the absence of RPE differences (5.1 vs. 5.5), it is possible that the protocol with the *FORM Goggles* was less demanding for the swimmers by allowing them to adapt and dose the effort required while performing the task. In addition, this instrument could allow coaches to focus their time and attention on other aspects, such as technical and/or qualitative assessment, not having to provide feedback related to the swimming pace. In addition, performance times are saved and stored, allowing for more in-depth analysis.

The main limitation of this study was the small number of participants. Between swimmers there may be differences due to level, sex, age, etc., and the repetition could also have an influence, mainly due to fatigue and/or the improvement of pace control in the last repetitions. Therefore, our results had a limited statistical power, but we must bear in mind that it is difficult to have volunteers who commit to participate in numerous test sessions. Also, in experiment two, a situation without any feedback could have been included to compare with other feedback situations (Altavilla et al., 2018; Pérez et al., 2009). However, in this study it has been decided not to introduce this condition. This is due to the competitive context of the present study (competitive swimming), in which a situation where swimmers do not receive any feedback does not happen in a real way in training. The most common is to have a coach who tells the swimmer the time spent in the series at the end of its execution. Furthermore, in the present study, 100 m series were performed to get closer to a situation that occurs in a real way in the daily training of swimmers. Although in series of middle-distance (200-400 m) or longer distance (800 m or more) where pace control strategies are more relevant, the differences with respect to the target time could be greater (McGibbon et al., 2018) swimmers specialised in these distances might find a better application of these training control systems. Therefore, as future line of research, it would be interesting to observe these types of feedback in longer training series, where pace control strategies become more relevant. On the other hand, it would also be valuable to study the effect of this type of feedback on recreational swimmers with less training experience. In this case, the differences between target time and actual time could be larger, and the use of this tool would bring a greater benefit.

The swimming training control devices *FORM Smart Swim Goggles* and *Finis Stopwatch* offered validity and good level of agreement with respect to an accurate photogrammetric system for the variables total and partial times and number of strokes. The *Garmin Swim 2 Watch* provided larger errors, even above the mean smallest meanwhile change (mathematically set at 0.38 s) for the partial times. On the other hand, there were significative differences on pace control between the feedback provided by *FORM Smart Swim Goggles* (concurrent feedback) and the *Finis Manual Sopwatch* (feedback provided after every partial). The results showed that the concurrent feedback provided by *FORM Smart Swim Goggles* could offer greater advantages than the traditional feedback provided at the end of each series, since the swimmers were closer to the target time. This new tool (*FORM Smart Swim Goggles*) has numerous advantages for extensive use in both training and research.

## Geolocation information

North latitude: 37º 12’ 19.229”

West longitude: 3º 35’52.246”


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## Declaration of interest statement

The authors declare that they have not any conflict of interest into report.

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## Figure captions

**Figure 1.** Experimental set-up followed in the two experiments (*ASPA*: Automatic swimming performance analysis).

**Figure 2.** Above (a, b, c): Bland Altman plots for the 25-m partial times, using the *ASPA* system as reference. Below (d, c): Bland Altman plots for the 25-m partial number of strokes. The long dash line represents 0.96 standard deviation from the mean.

**Figure 3.** Percentual time to target time per 100 m-partial and per feedback device (Mean ± SE).

## Table captions

**Table 1.** Total and 25-m partial times of the 200 m test (mean ± SD) by the swimming feedback device.

**Table 2.** Error magnitude of the 200 m test total and 25 m partial times by swimming feedback device.

**Table 3.** Summary of the general linear model including PTT as dependent variable and feedback device, swimmer and 100 m partial as independent (categorical) variables.