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Original research

Comparing three underwater trajectories of the swimming start

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ABSTRACT

Once a swimmer enters the water they will not increase velocity, instead they will decelerate. One factor that will influence the velocity maintained during the underwater phase is the trajectory the swimmer adopts.

Objectives: Once a swimmer enters the water they will not increase velocity, instead they will decelerate. One factor that will influence the velocity maintained during the underwater phase is the trajectory the swimmer adopts. This study aimed to identify how different underwater trajectories affect start time in elite swimmers.

Methods: Fourteen swimmers performed three dives: a shallow dive with little underwater time (Dive 1), a flatter dive with intermediate time underwater (Dive 2) and a deep dive with lengthy underwater time (Dive 3). The proprietary 'Wetplate' analysis system was used to collect performance time (time to 15 m) and other dive parameters.

Results: A mixed modelling approach found Dive 1 was significantly slower than Dive 2 and 3 (time to 15 m). This indicated that both a shallow or deep dive slowed overall performance, with shallower dives adversely affecting performance the most.

Conclusions: On average, using a flatter trajectory with a maximum depth of -0.92 ± 0.16 m similar to Dive 2 may prove to be beneficial to start performance. More research is needed to examine the interaction between drag and depth for individual swimmers to better understand the mechanisms influencing these findings and to further explore the notion of an ideal underwater trajectory.

1. Introduction

Start time, which consists of the on-block, flight and underwater phases, has been strongly correlated to overall performance in competitive swimming.[1] The on-block phase is defined as the time between the starting signal and the time when the swimmer's feet leave the blocks. The flight phase is the interval between the swimmer's toe leaving the block and the swimmer's head making contact with the water, while the underwater phase is defined as the interval between head contact with the water and the head re-surfacing to commence free swimming. Furthermore, total start time is calculated as the time from the starting signal to when the centre of the swimmer's head reaches the 15 m mark.[1]

The underwater phase is the longest phase of the start and has been shown on multiple occasions to be the most decisive in determining efficient overall start performance, because it is when the swimmer is travelling at their fastest through the water.[1–3] This phase is crucial to overall race performance as it has also been shown to account for 95% of variance in start time.[4,5] There are a number of factors that will affect the swimmer after they enter the water that will determine how much velocity is maintained during the underwater phase and in turn the overall outcome of the start. These include being as streamlined as possible, starting underwater undulatory swimming after about 6 m and generating propulsive kick using only the feet and legs during the underwater water kick phase.[6] The swimmer can also vary the depth at which they are travelling, although this will affect the amount of drag acting on the swimmer and has implications on the trajectory of the underwater phase.[2,3,7] Consequently, the trajectory and depth the swimmer is travelling at is important to minimising the effect of drag and decreasing deceleration through the underwater phase.

The ideal underwater trajectory has not yet been determined for the kick-start technique using the new Omega OSB11 starting block. Given the already established importance of trajectory and depth for better start performances, the aim of this study is to compare three underwater trajectories used by swimmers to determine how they influence start performance. It is hypothesised that the ideal underwater trajectory will be an optimal depth to reduce the amount of drag acting on the swimmer, while

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still enabling the swimmer to travel in the desired horizontal direction.

2. Method

This study was approved by the Australian Institute of Sport (AIS) Performance Research Ethics Committee. Fourteen swimmers (11 male, 3 female, 19 ± 1 years) were recruited from the AIS and other state institute swimming programmes around Australia. All swimmers were considered highly competitive, with two Olympic representatives, two World Championship representatives and eight Australian National Open Finalists. All swimmers were able to qualify for the National Championships in the 100 m freestyle (53.10 s for male, 59.00 s for female) and had at least 5 years of competitive swimming experience at the national level. Only freestyle was chosen for this study because a previous study by Tor et al.[5] found that there were differences during the underwater phase between freestyle and butterfly.

Prior to testing, each swimmer performed their usual pre-race warm-up and were given at least three practice trials per dive type to ensure that they were able to perform each condition adequately. Swimmers were asked to perform a series of dives at three depths. The depths were categorised as Dive 1, Dive 2 and Dive 3. Dive 1 is typically characterised by swimmers resurfacing as fast as possible with minimal underwater kick. During Dive 1 the swimmers were asked to resurface and commence free swimming almost immediately after entry. Dive 2 was a gradual descent followed by a gradual ascent. For this dive, the swimmers were asked to dive deeper and aim to resurface around the 10 m mark. Finally, in Dive 3 the swimmers were asked to dive down deep and resurface to commence free swimming at the 15 m mark.

To assist the participants in achieving the prescribed trajectories, brightly coloured weighted markers were placed at 5 m, 7.5 m and 9 m on the bottom of the pool, to indicate the point at which the participants needed to begin rising to the surface in order to achieve Dive 1, Dive 2 and Dive 3 trajectories respectively. The distances that the markers were placed at was determined from a previous study by Tor et al.,[5] which found that the mean horizontal distance of maximum depth for elite swimmers is 6.06 m with a standard deviation (SD) of 0.97 m. Therefore, the markers were placed at −1 SD (5 m), +1.5 SD (7.5 m) and +3 SD (9 m) according to the results of that previous study.

The swimmers performed 12 dives with maximum effort to 15 m (4 dives for each dive type) with 2 min rest in between each dive. The 12 dives were completed over two testing sessions (one day rest in between each session) to avoid any fatigue effects and to ensure that each trial was performed maximally by the swimmer; six dives per session. Each swimmer performed two of each dive type during the session in a randomised order.

Each dive trial was tested using the Wetplate Analysis System. The Wetplate Analysis System is a proprietary system developed by the AIS Aquatic Testing, Training and Research Unit (ATTRU) and consists of an instrumented starting block with the same dimensions as the Omega OSB11 starting block (that is used at all major international competitions) and a series of high-speed cameras.[8] The reliability of these parameters has been previously established by Tor et al.[15] Performance time was measured using a second proprietary system, 'Swimtrak', which is made up of eight analogue video cameras (Samsung, SCC-C4301P) located perpendicular to the plane of motion at 0 m, 2.5 m, 5 m, 7.5 m, 10 m, 15 m, 20 m and 25 m and positioned approximately 5 m above the surface of the pool.

Female and Male participants were combined in all analyses to increase statistical power. Although differences in gender have been identified in a previous study by Tor et al.,[5] these differences were accounted for by adding gender as a covariate in the analysis. The data was coded to identify each dive type and gender. All of the dive conditions were pooled on a group basis for analysis, i.e. 56 trials for each dive condition. Prior to mixed modelling, each parameter was graphed for visual inspection to screen for outliers. As there were no outliers, all data was included in further analysis. Mixed modelling was used to make comparisons between each dive type. Start performance was defined as Time to 15 m. The fixed factors were the dive type and a new variable, which was created to allow for an interaction to be included for gender and dive type (gender × dive type), while the random effects were the participants' given name. The new variable was added to each model because a limitation of SPSS Statistical Package is that pairwise comparisons for an interaction term are not generated unless a new variable is created. Therefore, the new variable allowed for pairwise comparisons to be made between each group combining gender and dive type separately. The same model was used for all analyses; however each parameter was included as a separated dependent variable. Pairwise comparisons with a Bonferonni correction were then used to make specific comparisons between each parameter. Significance was set at $p < 0.05$, although difference in mean and 95% confidence intervals were reported as well, to provide information about the extent of the differences between each group.

3. Results

The descriptive statistics for each dive type (Table 1) confirmed that each dive type was executed as instructed. These trajectories were chosen because they are the three most widely used trajectories used by elite swimmers. The above-water parameters (prior to entry into the water) showed no significant differences for all dive types, with the majority of differences only seen in the underwater water parameters.

For the underwater parameters, there was a significant main effect ($F_{2,150} = 3.37$, $p = 0.04$) for maximum depth with an interaction for gender (Fig. 1). This was the only parameter to show a significant interaction for gender. Although, the plots of this parameter revealed a similar trend regardless of gender, this was most likely due to the smaller number of female subjects and will not affect the outcomes of the study. Total underwater water time also varied between dive conditions ($F_{2,150} = 65.19$, $p < 0.001$). Dive 3 spent the most time underwater (4.16 s), followed by Dive 2 (3.07 s) and Dive 1 (1.88) respectively. This was closely linked to the significant differences between each dive type also exhibited for breakout time ($F_{2,150} = 65.10$, $p < 0.001$) and breakout distance ($F_{2,150} = 47.40$, $p < 0.001$). Time of first kick also differed between dive types ($F_{2,150} = 23.23$, $p < 0.001$), specifically there were differences between Dive 1 and Dive 2 (−0.13 s, −0.18 to −0.07, $p < 0.001$) and Dive 1 and Dive 3 (−0.14 s, −0.19 to −0.08, $p = 0.003$).

There were also significant main effects between each dive type for time to 15 m ($F_{2,150} = 7.62$, $p = 0.001$). Dive 1 was significantly slower than Dive 2 (difference in mean, 95% confidence intervals, p value) (0.08 s, 0.03 to 0.13, $p = 0.001$) and Dive 3 (0.06 s, 0.01 to 0.12, $p = 0.01$). This was similar for time to 10 m ($F_{2,150} = 29.86$, $p < 0.001$), with Dive 1 also being slower than Dive 2 (0.09 s, 0.05 to 0.13, $p < 0.001$) and Dive 3 (0.12 s, 0.08 to .15, $p < 0.001$) regardless of gender. However, there was no significant main effect for time to 5 m ($F_{2,150} = 0.753$, $p < 0.001$). The significant pairwise comparisons of each parameter are displayed in Table 1.

In terms of average velocities, 0–5 m showed no significant difference. However, there were significant main effects for average velocity between 5 and 7.5 m ($F_{2,150} = 16.34$, $p < 0.001$) and average velocity between 10 and 15 m ($F_{2,150} = 6.21$, $p = 0.003$). Pairwise comparison between each dive type showed significant differences