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How Should the Transition from Underwater to Surface Swimming Be Performed by Competitive Swimmers?

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Abstract: Despite the increasing importance of the underwater segment of start and turns in competition and its positive influence on the subsequent surface swimming, there is no evidence on how the transition from underwater to surface swimming should be performed. Therefore, the aim of the present study was to examine the role of segmental, kinematic and coordinative parameters on the swimming velocity during the pre-transition and transition phases. A total of 30 national male swimmers performed 4 × 25 m (one each stroke) from a push start at maximum velocity while recorded from a lateral view by two sequential cameras (50 Hz), and their kinematic and coordinative swimming parameters were calculated by means of two-dimensional direct linear transformation (DLT) algorithms. Unlike pre-transition, backward regression analysis of transition significantly predicted swimming velocity in all strokes except breaststroke (R^2 ranging from 0.263 in front crawl to 0.364 in butterfly). The inter-limb coordination was a predictor in butterfly stroke ($p = 0.006$), whereas the body depth and inclination were predictors in the alternate strokes (front crawl ($p = 0.05$) and backstroke ($p = 0.04$)). These results suggest that the body position and coordinative swimming parameters (apart from kicking or stroking rate and length) have an important influence on the transition performance, which depends on the swimming strokes.

Keywords: kinematics; inter-limb coordination; performance; direct linear transformation

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1. Introduction

In the last few years, the importance of the underwater segment of the start and turns in swimming competitions has increased both quantitatively and qualitatively. The contribution of underwater swimming to the total race distances has considerably increased over the last 20 years [1] and elite swimmers now spend between 15 and 25% of the 100 m race distances underwater [2]. Additionally, swimmers achieving the fastest underwater velocities (especially on 100 m events) or the longest underwater distances (on 200 m events) have a critical advantage on their performances during World Championships [3]. The lower drag resistance experienced by swimmers underwater [4] as well as the improvement on the undulatory techniques [5], allow swimming competitors to achieve the fastest race velocities and to prioritize these segments over the mid-pool swimming techniques.

The benefits of the underwater swimming for competitive swimmers also include a transfer of momentum to the subsequent surface swimming during starts and turns [2]. Elite swimmers exhibited 5–10% faster swimming velocities after the start emersion compared to mid-pool swimming, with small increases of both stroke rate (SR) and length (SL) [2]. After the turn, those swimmers achieving the longest underwater distances (backstroke and butterfly) also obtained 5–6% faster velocities at emersion compared to mid-pool [2]. This positive impact of underwater on surface swimming can be achieved if a correct transition from underwater (the so-called breakout) is performed. Swimmers must restart their arm propulsion at this point and they no longer maintain the hydrodynamic position they adopt during underwater kicking [6]. While doing so, they must optimize the stroke timing in order to finish the arm pull (and begin their aerial recovery) when the head reaches the water surface. Additionally, in this phase, swimmers change location (from fully submerged to emerged at water surface) that could have implications on active drag [7], associated with an increase in wave drag [8]. The simultaneous (butterfly and breaststroke) or alternate (front crawl and backstroke) arm stroke techniques, the supine (backstroke) or prone (front crawl, butterfly and breaststroke) body position and the beginning of the flutter kick versus the undulatory kick [5] are other constraints that swimmers must handle in this phase.

In relation to the beginning of arm propulsion, previous studies have quantified the inter-limb coordination by measuring the time gap between the propulsive actions of arms and/or legs. Chollet et al. [9] found positive correlations between shorter inter-limb time gaps and the free-swimming velocity, although dependent on the swimmer skill [10], stroke [11], gender [12] and the use of added resistance [13]. For the swimmers' body positions, both body inclination and body depth have been examined as the different locations of the centre of mass and centre of flotation cause an active rotational torque, which influences the body projected frontal area [14]. An increased body angle has been negatively correlated with swimming underwater velocity [15] and surface velocity [16] due to increased projected area and, therefore, frontal drag [17,18]. On the other hand, body depth has been correlated positively with underwater velocity [19] due to decreased swimming resistance [20,21]. Finally, for the underwater kicking, Arellano and colleagues [22,23] indicated that the underwater undulatory swimming (UUS) velocity is dependent on kicking kinematics (i.e., kicking rate, amplitude, and length (distance per kick)), the kicking rate being the most important parameter. When competitive swimmers begin the first UUS cycle underwater, they are located at relatively greater depth (-0.92 m from water surface) [24] and display greater kicking rate and amplitude compared to the end of underwater swimming [25].

Although these kinematic parameters have been examined in the mid-pool swimming or in the underwater undulatory kicking phases, no information about their role in the transition from underwater to surface swimming has been explored as yet. For example, it is unknown whether great depth could be beneficial during transition given that it would require greater body angles (i.e., higher active drag) to reach water surface in a relatively restricted distance. Therefore, the aim of the present study was to examine the role of the segmental, kinematic and coordinative parameters on the swimming velocity during the pre-transition and transition phases of the push start. Considering the positive influence of underwater on the subsequent surface swimming, it could be expected that swimmers would decrease the time gaps between the propulsive arm actions, would minimize body inclinations and would maximize USS velocity for faster transitioning velocity.

2. Materials and Methods

2.1. Participants

A total of thirty national level male swimmers (16.80 ± 1.44 years, 1.73 ± 0.05 m and 64.56 ± 6.78 kg) with a personal best time in the 100 m front crawl, backstroke, butterfly or breaststroke events within the 85% of world record (86.03 ± 2.34%), volunteered to participate in this study. Inclusion criteria for the experiment comprised a continuous attendance to the training sessions (9 in water sessions per week) as well as the absence of a major injury in the last three months before the experiment. The participants (>18 years) or their legal guardians (<18 years) signed a written consent document to participate in the study that was approved by the local Ethics Committee (number 45/2018) and in accordance with the Declaration of Helsinki [26].

2.2. Procedure

Swimming tests took place from 09:00 h until 14:00 h in a 50 × 25 m pool heated to 28° C and with 65% humidity. Participants maintained their usual training routine in the previous days before data collection and were asked to avoid physical activities (that were not related to swimming practice) at least 24 h before every session. Additionally, the participants were asked to avoid heavy food consumption and energy drinks at least 3–4 h before each test session. In a longitudinal lane of a pool, swimmers performed four repetitions (one of each stroke in a random order) of 25 m at their maximal velocity from a push start and with a 3 min rest between them. The push start consisted of swimmers pushing off the wall in-water from an initial position where one arm was in contact with the starting wall and the other arm was in-water. Swimmers were instructed to start with their feet at approximately one meter below the water surface and to push off the wall at the level of the feet to minimize the effect of wave drag [27]. Prior to the trials, black joint markers of round shape and made of waterproof adhesive tape (diameter 25 mm) were attached to the wrist, shoulder, hip, knee and ankle joint centers. Then, swimmers conducted a standardized warm-up which consisted of 10 min of warm-up activities on dry land and 20 min (≈1.0 km) in the water.

2.3. Data Acquisition and Processing

Swimmers were recorded with two cameras placed behind the underwater windows (JVC GY-DV500E, 50 Hz, 1/1000 s) and with their optical axis perpendicular to the sagittal plane of the swimmers. Both cameras were located 12 m at the side of the swimmers' lane, the first camera being at 7.5 m and the second camera at 15 m from the starting wall. Swimming recordings were manually digitized and temporally coded by an experienced observer using biomechanical model of four points (shoulder, hip, knee and ankle). Two-dimensional direct linear transformation (2D-DLT) algorithms [28] were employed to transform the two dimensional screen coordinates (in pixels) to real meter coordinates. A rectangular structure of PVC (2 m high and 5 m wide) with known coordinates located in the swimmer's plane of movement was used for the camera's calibration prior to recordings in each camera view. The origin of the reference system was placed on the starting wall of the pool at the water surface level [29], with the horizontal and vertical axes aligned towards the starting direction and the above water direction, respectively.

The transitioning from underwater to surface swimming was divided in two phases: (1) pre-transition—the last underwater kicking action (downward kick plus upward kick movements, [30]) before the beginning of arm propulsion and (2) transition (breakout)—the first complete arm stroke cycle after pre-transition (Figure 1). The pre-transition was defined from the swimmers' feet in the highest position (or lowest position in backstroke), whereas the transition phase was defined from the swimmers' hands separation to the first or second water entry, respectively, for the butterfly or alternate strokes. In breaststroke, both pre-transition and transition phases were defined from the maximum flexed knee position on the first and subsequent breaststroke kick after the underwater arm pullout.

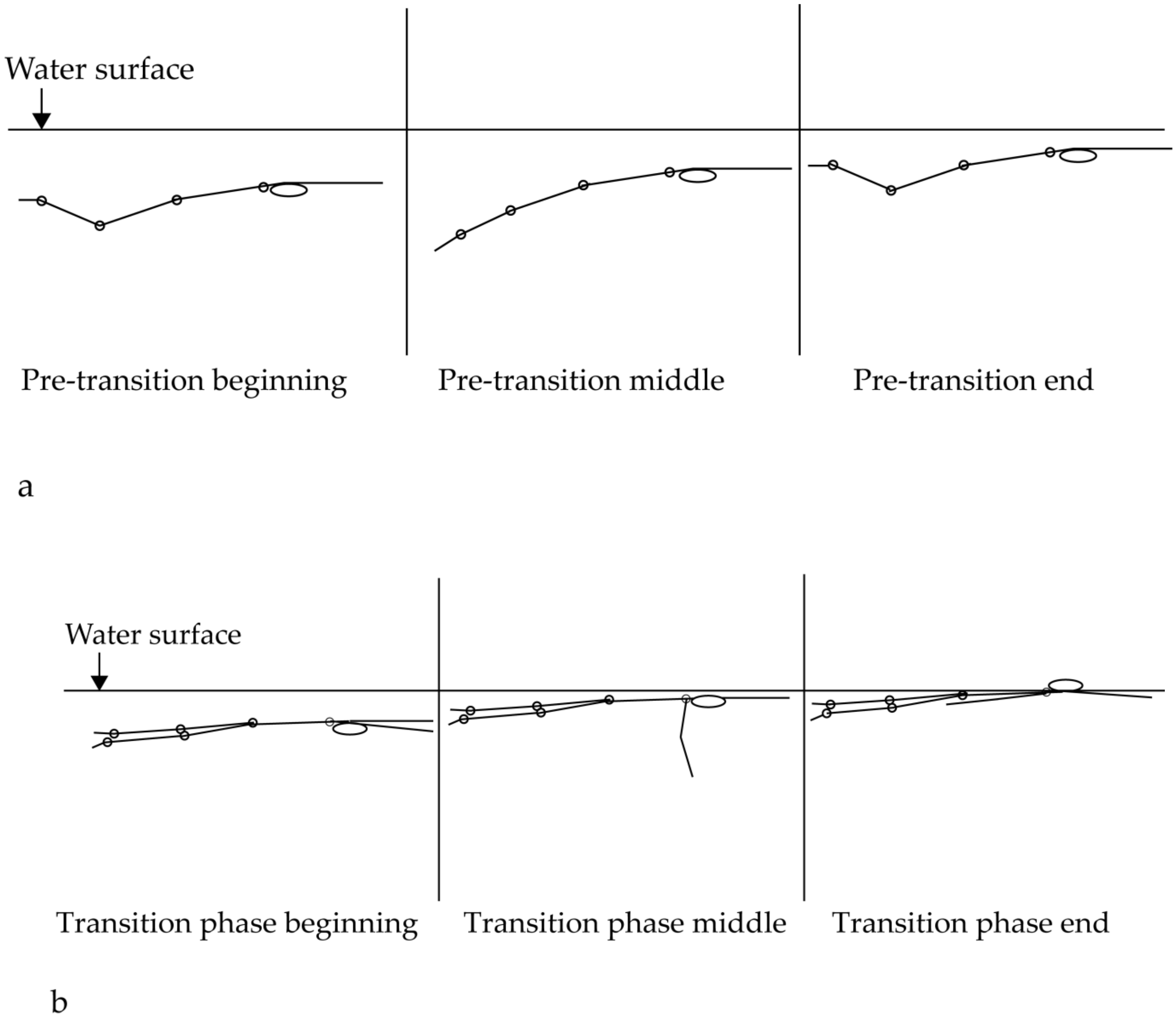

Figure 1. Schematic illustration of the pre-transition (**a**) and transition (**b**) phases from underwater to surface swimming.

2.4. Variables Definition

For each phase, the following kinematic parameters were calculated. In relation to the body position: (i) trunk inclination as the angle (°) between shoulder-hip line and horizontal, (ii) body inclination as the angle (°) between shoulder-knee and horizontal and (iii) body depth as vertical distance from water surface to hip position at the beginning of pre-transition or transition phases. Both inclination parameters were obtained at the beginning (hand separation from the hydrodynamic kicking position) and in the middle (hand pulling on the shoulder vertical) of the arm pull and were denoted as inclination 1 and inclination 2, respectively. For the kicking parameters: (i) kick amplitude was the vertical displacement of the ankle from the highest to the lowest position, (ii) kick length was the horizontal displacement of the hip in an entire kick (ascending and descending) cycle, and (iii) kick rate, as the inverse of time employed in an entire kick. For the stroking parameters: (i) SR was considered as the inverse of the time needed to complete one full stroke cycle, (ii) SL was the horizontal displacement of the hip during one stroke cycle and (iii) swimming velocity the multiplication of SL and SR [31].

For the coordinative parameters, the selected events whose lag times were calculated were adapted from previous work on the four competitive strokes [11]. Those lag times were then divided by the duration of the swimming cycle and multiplied by 360 degrees in order to get discrete relative phase (DRP) angles [32]. In front crawl and backstroke, two lag times (expressed as discrete relative phase angles) were calculated: DRP1, the end of the propulsive action (arm exit in front crawl and arm extension in backstroke) of the first pulling arm and the beginning of the propulsive action (arm pull) of the second pulling arm; DRP2, the end of the propulsive action of the second pulling arm and the beginning of the propulsive action of the third pulling arm (during the second swimming cycle). In butterfly, four discrete relative phase angles: DRP1, the hand separation from the streamlined position and the feet in the highest position during kick phase; DRP2, the beginning of the arms' pull and the feet in the lowest position in the kick cycle; DRP3, the beginning of the arms' push and the feet in the highest point of the kick period; DRP4, the arms' exit from water and the feet in the lowest position of the kick cycle. Finally, in breaststroke four discrete relative phase angles were obtained: DRP1, the end of leg propulsion (leg extension) and the beginning of the arm propulsion (arms' backward movement); DRP2, the feet together after leg extension and the beginning of arm propulsion (arms' backward movement); DRP3, the beginning of arm recovery (arms moving forward) and the beginning of leg recovery (legs moving forward); DRP4, the end of arm recovery (arms fully extended) and the end of leg recovery (legs fully flexed).

2.5. Data Analysis

After checking the normal distribution of the data by Kolmogorov−Smirnov test, parametric statistics was applied. One-way ANOVA (stroke) was applied in order to examine differences within the pre-transition and transition phase regarding kinematics (velocities, lengths and frequencies) and segmental variables (body and trunk inclinations, body depths). When main effects were identified, Bonferroni adjustments with effect sizes (ES, as partial eta-squared values) were applied to interpret meaningful effects. Multiple regression analysis (backward model) was used to identify the influence of body position and coordinative parameters on the average swimming velocity. Stroking or kicking parameters (length and rate) were not input variables for backward regression analysis due to their direct influence on swimming or kicking velocity, respectively. In addition, correlation coefficients (Pearson product moment correlation) were identified between each independent variable and dependent variable (velocity). The threshold values of the correlation coefficient that represented small, moderate, large, very large and nearly perfect correlations were 0.1, 0.3, 0.5, 0.7 and 0.9, respectively, according to recommendations in the literature [33]. Finally, an analysis of variance on the stroke was performed for all kinematic and coordinative parameters. All the analysis was performed using Statistical Package for Social Sciences (IBM SPSS for Windows, Version 20.0.; IBM Corp., Armonk, NY, USA), arranging data by stroke (front crawl, backstroke, butterfly and breaststroke). Data were expressed as mean ± standard deviation with 95% confidence intervals, unless otherwise indicated.

3. Results

Table 1 shows the kinematic parameters of competitive swimmers during pre-transition and transition phases of the push start. In the pre-transition phase, there were no differences on the kicking parameters of the front crawl, backstroke and butterfly strokes. However, there was stroke effect on the body depth (F = 18.18, p = 0.000, ES = 0.31), trunk inclination 1 (F = 13.06, p = 0.000, ES = 0.24), trunk inclination 2 (F = 5.82, p = 0.001, ES = 0.13) and body inclination 1 (F = 12.71, p = 0.000, ES = 0.24). In the transition phase, differences were observed between strokes on the SL (F = 6.03, p = 0.001, ES = 0.13) and SR (F = 54.09, p = 0.000, ES = 0.57) values, as well as on the majority of segmental parameters: body depth (F = 39.47, p = 0.000), trunk inclination 2 (F = 17.97, p = 0.000, ES = 0.31), body inclination 1 (F = 51.77, p = 0.000, ES = 0.57) and body inclination 2 (F = 8.22, p = 0.000, ES = 0.17).

Table 1. Segmental kinematics—mean (standard deviation)—of competitive swimmers when transiting from underwater to surface swimming in all four strokes.

	Front Crawl	Backstroke	Butterfly	Breaststroke
Pre-transition				
Kick length (m/cycle)	0.77 (0.12)	0.72 (0.10)	0.77 (0.12)	3.66 (0.50)
Kick rate (cycles/s)	2.15 (0.31)	2.14 (0.30)	2.14 (0.35)	0.39 (0.07)
Kick amplitude (m)	0.29 (0.06)	0.27 (0.18)	0.31 (0.06)	-
Body depth (m)	−0.39 (0.13)	−0.62 (0.22) ^{a}	−0.36 (0.12) ^{a}	−0.53 (0.16) ^{ac}
Trunk inclination 1 (°)	16.20 (5.26)	8.25 (6.13) ^{a}	16.13 (5.35) ^{a}	10.56 (7.30) ^{ac}
Trunk inclination 2 (°)	4.58 (3.07)	9.01 (5.22) ^{a}	4.91 (3.57) ^{a}	7.42 (6.38)
Body inclination 1 (°)	14.31 (5.07)	6.17 (4.55) ^{a}	13.14 (4.87) ^{a}	9.25 (8.19)
Body inclination 2 (°)	6.44 (3.96)	4.42 (3.70)	6.32 (4.50)	6.63 (5.39)
Transition				
Body depth (m)	−0.20 (0.11)	−0.52 (0.17) ^{a}	−0.20 (0.11) ^{a}	−0.34 (0.14) ^{abc}
Trunk inclination 1 (°)	9.00 (4.77)	9.02 (7.98)	9.00 (5.07)	9.80 (5.77)
Trunk inclination 2 (°)	7.45 (3.67)	12.78 (6.07) ^{a}	14.28 (6.76) ^{b}	17.50 (6.39) ^{bc}
Body inclination 1 (°)	11.66 (6.46)	6.37 (4.49) ^{a}	12.62 (5.56) ^{a}	25.26 (6.83) ^{abc}
Body inclination 2 (°)	9.66 (4.27)	12.98 (5.99)	11.15 (4.75)	15.42 (5.76) ^{ac}

Note: a, b and c superscripts denote statistical differences ($p < 0.05$) from first, second or third left column.

Figure 2 shows relationships of the pre-transition and transition parameters with the average velocity of each phase. During pre-transition, average velocity was small to moderately correlated with body depth in front crawl ($r = 0.262$) and butterfly ($r = 0.283$) strokes, whereas no correlations ($p > 0.05$) were observed for the body inclination. For the kicking variables, kick rate and kick length (but not amplitude) were moderate to largely correlated with faster velocities in all strokes, except the backstroke kicking rate. During transition, body inclination and body depth were negatively correlated with velocity in backstroke whereas no relationships were observed for the remaining strokes. In this phase, some of the coordinative parameters were moderately related to transition velocity, indicating shorter time gaps related to faster velocities except for DRP2 in front crawl and DRP3 in breaststroke.

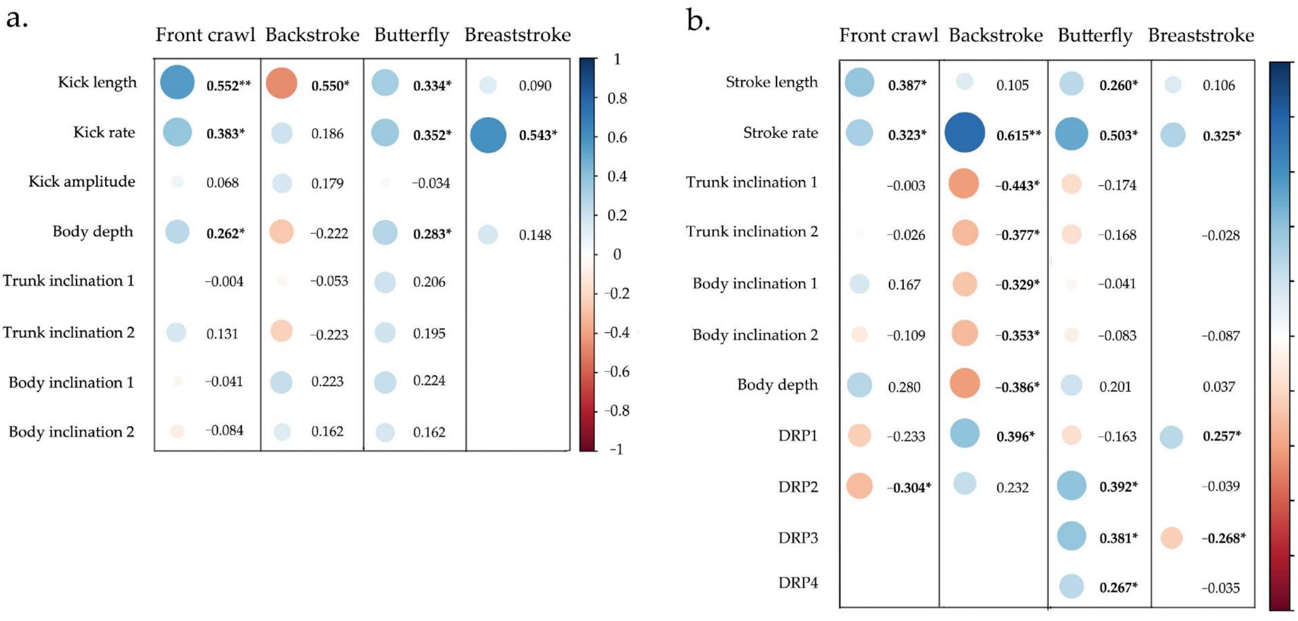

Figure 2. Relationships between the kinematic, segmental and coordination variables with average velocity of the competitive swimmers in the pre-transition (**a**) and transition (**b**) of the push start. Note: * denotes correlations at a $p < 0.05$ level.

Backward regression analysis of pre-transition phase performance revealed that the body position parameters did not statistically predict ($p > 0.05$) the average velocity in this phase. In transition (Table 2), the regression model significantly predicted swimming velocity in all strokes except breaststroke (with R^2 ranging from 0.263 in front crawl to 0.364 in butterfly). All inclination and depth parameters were predictors of velocity in front crawl ($p = 0.044$) and backstroke ($p = 0.039$) whereas all coordinative parameters were predictors in butterfly ($p = 0.006$).

Table 2. Backward regression analysis of the transition phases in all four strokes.

Dependent Variables	**Backward Regression Model**			
	Front Crawl	**Backstroke**	**Butterfly**	**Breaststroke**
Beta standardized coefficients				
Body depth	0.32	−0.40	1.80	0.28
Trunk inclination 1	−0.36	0.32		
Body inclination 1	0.38	−0.30		
DRP1		0.33	−0.52	0.82
DRP2	−0.35		0.62	−0.49
y-intercept (constant)	1.67 ± 0.08	1.92 ± 0.12	1.69 ± 0.08	1.25 ± 0.07
R^2	0.263	0.321	0.364	0.230
R^2 adjusted	0.154	0.213	0.293	0.125
Standard error of estimate	0.161	0.178	0.152	0.111
F	2.407	2. 959	5.141	2.191
p	0.044 *	0.039 *	0.006 **	0.118
Number of observations	30	30	30	30

Note: beta standardized coefficients presented for independent variables where $p < 0.05$.

4. Discussion

The aim of the current study was to examine the factors relevant for swimming performance during transition from underwater to surface swimming by applying correlation and regression analysis. Previously, it had been indicated that swimming velocities of elite swimmers after emersion from underwater were faster than during mid-pool swimming [2]. However, no information about how swimmers should perform this transition phase had been revealed. Our results indicate that body position and coordinative swimming parameters (besides SR and SL) have an influence on the transition performance, which magnitude depends on the swimming strokes.

4.1. Pre-Transition Phase

Before swimmers emerged from underwater, during the last underwater kicking cycle (pre-transition phase), the body position parameters (depth and inclination) did not statistically predict the forward velocity. At this point, only the kicking parameters (kicking length and rate) were correlated with velocity (Figure 2) and this highlighted the importance of kicking propulsion rather than technical position of the body underwater [34]. Values of kicking kinematics during pre-transition were similar to those obtained in USS by Arellano et al. [22,23], Hochstein et al. [35] and Alves et al. [36] although the magnitude of correlations with forward velocity were in line with previous research [23] both for the kicking rate ($r = 0.519$ compared to $r = 0.383$ in the present research) and kicking length ($r = 0.630$ compared to $r = 0.552$). The kicking amplitude, on the other hand, did not present statistical relationships with pre-transition velocity.

The body position parameters on the pre-transition phase were between 6° and 16° for the body inclination (respect to horizontal) and from −0.36 m (butterfly) to −0.62 m (backstroke) for the body depth (Table 1). These inclinations were in line with previous data from Arellano et al. [22] who reported body angles of 17° degrees during USS. However, the pre-transition body depth was obviously lower than the optimum (from −0.74 to −1.03 m) for UUS [24]. These data, interestingly, suggest that, when transiting for underwater to surface swimming, swimmers diminish depth but maintain body inclinations with a correct alignment almost parallel to water surface, not different from the UUS [15]. Otherwise, there would be an increase in frontal drag [7] with a concomitant velocity reduction [37]. As previously mentioned, the body position parameters presented small or no correlations with pre-transition velocity. However, the direction of relationships for the body depth depended on strokes (Figure 2). In backstroke, where body depth was greatest, negative correlation between depth and forward velocity were detected. On the other hand, in the ventral techniques (where body depth was lower) greater depths were related to faster velocities. This highlighted the stroke-dependent strategies when transiting from underwater to surface swimming.

4.2. Transition Phase

During transition, the swimmers' SR in all strokes showed greater correlations (medium to large) with average velocity than the SL (small to medium) (Figure 2). This was in line with the increased SR values of elite swimmers after start and turn emersion compared to mid-pool swimming [2], due to a shorter relative duration of the propulsive stroke phases. In a situation of an increased overall drag due to wave drag emergence [8], unfatigued swimmers [38], probably prioritized to increase the SR to overcome resistance. Compared to mid-pool swimming, the stroking parameters during transition exhibited lower relationships with forward velocity (moderate to large) than previously reported (for instance, r values were from 0.87 to 0.92 for the SR [39–41]). This highlights the specific characteristic of the transition phase, where other kinematic factors (depth, inclination . . .) besides stroking parameters seem to have an important role for building velocity. Indeed, the regression models proposed in the present research, based on the body position and inter-limb coordination of transition, explained up to the 30% of the average velocity for the butterfly stroke, which represents a meaningful finding for swimmers and coaches.

When beginning the transition phase, swimmers in the present research were located between 0.20 and 0.52 m below the water surface and, interestingly, the body inclinations averaged 9° degrees regardless of stroke. These body inclinations were similar (10.68°) to those reported by Kjendlie et al. [16] in surface swimming. Probably, maximum velocity at which swimming trials were performed in the present research and the swimmer's skill level helped them to counteract the active rotational torque and maintaining a close body alignment to horizontal [14,42]. This could be the reason why the correlations between body inclinations and average velocity were low, especially in alternate strokes where no undulations were present. For the body depth, values close to 0.4 m below the water surface were in line to the minimum suggested by Lyttle et al. [20] to avoid wave drag. Interestingly, at this point, backstroke swimmers presented the deepest body positions compared to the ventral strokes that could be influenced by the more incongruent body side (compared to prone position) approaching water surface that would cause higher friction and form drag [43]. However, additionally, different arm pull position in backstroke compared to the ventral strokes (hand trajectory below or lateral to the body position) could explain depth differences.

For the coordinative parameters, a shorter time gap between the arm propulsion of both backstroke arms was related to faster transition velocities, which is in line with positive correlations between inter-limb coordination and free swimming velocity [9,40]. However, surprisingly, the second discrete relative phase in front crawl was negatively correlated with transition velocity (more time gap, faster velocity). This could be related to the role of breathing on the inter-limb coordination [44] after the second arm pull, as swimmers are usually encouraged to avoid breathing on the first arm propulsion after underwater. In the simultaneous strokes, shorter time gaps between the arm and leg butterfly propulsion were correlated with faster velocities during transition, indicating a preferable propulsion continuity to overcome drag forces. In breaststroke, on the contrary, longer times gaps between the arm and leg propulsion (DRP1) were related to faster velocities. Although motor continuity is generally recommended [45], breaststroke swimmers in transition from underwater must recover arms from the underwater pullout (hands close to thighs) instead of a regular arm pull. Therefore, the time gap between the propulsive phases of arms and legs could be expected to be longer. This represents an interesting point linked to the correct coordination of the underwater pullout [46].

According to regression analysis of transition-phase, the body position and inter-limb coordinative parameters of competitive swimmers statistically predicted an important amount (between 15 and 29% depending on the stroke, Table 2) of the variance in the forward velocity. Statistical models included the body depth in all four strokes and the body or trunk inclination in the alternate strokes (front crawl and backstroke) for predicting transition performance, highlighting the importance of an appropriate body positioning when approaching the water surface. This should be performed while minimizing body depth and maintaining trunk inclination in backstroke but minimizing inclination in front crawl and maintaining depth with water surface. Obviously, on the simultaneous techniques (butterfly and breaststroke) where body undulations occur [47,48], the effect of trunk/body position for velocity was probably hindered. For the inter-limb propulsion coordination, in butterfly the time gaps related to the beginning of arm propulsion (DRP1 and 2) were included in the regression model. This data probably indicates that swimmers had to primarily adapt their arm to leg movements at the beginning of the arms propulsion (not in DRP3 and 4) when the body position was still underwater. For the alternate strokes, shorter times gaps at the end of the first arm pull in backstroke and longer time gaps at the end of the second arm pull in front crawl were included in the regression model. These results highlight the technical demands of swimmers who successfully adapted to the changing constraints of the transition phase, i.e., increased drag forces (underwater to surface swimming), modified body position (while ascending to water surface) and arm-to-leg propulsion (compared to primarily leg propulsion in underwater).

4.3. Study Limitations and Future Research

The present results provide interesting insights on how swimmers could organize their movements when transiting from underwater to surface swimming. The underwater kicking execution seems to be the priority for swimmers before transiting to surface swimming. However, during the first arm stroke cycle, swimmers should carefully control their body inclination and depth as well as the time gap between propulsive arm or leg movements. At this point, the stroking parameters are still the most correlated variables with average velocity, but some other kinematic parameters can represent meaningful improvements for competitive swimmers. It should be also acknowledged that further research is still needed for kinematics parameters during transition as all measurements in the present study were discrete values. Continuous analysis of swimmers' inclination and depth when transiting from underwater would provide greater information relating to their body positioning. This is especially relevant for alternate strokes, where inclinations and body depth were part of the regression model.

5. Conclusions

The body position and inter-limb coordination of competitive swimmers when transiting from underwater to surface swimming represented important factors on the swimming velocity, explaining from 15 to 30% on the variance during the first arm stroke cycle. Differences were observed from simultaneous to alternate strokes as, in the simultaneous strokes, the arm-to-leg coordination at the beginning of arm propulsion was the predictor variable of the swimming velocity, whereas for the front crawl and backstroke (alternate) the body depth and inclination seemed to be the key factors. In the pre-transition phase at the end of the underwater kicking phase, no influence of the body position was observed as the kicking parameters (length and rate) were the predictor variables for the average velocity. Swimmers should carefully control their body inclination and depth as well as the inter-limb coordination on the first arm stroke cycle after underwater swimming.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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