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Competitive Swimmers Modify Racing Start Depth Upon Request

Josh C. White, Andrew C. Cornett, Brian V. Wright, Alexander P. Willmott, and Joel M. Stager

To expand upon recent findings showing that competitive swimmers complete significantly shallower racing starts in shallower pools, 12 *more experienced* and 13 *less experienced* swimmers were filmed underwater during completion of competitive starts. Two starts (1 routine and 1 "requested shallow") were executed from a 0.76 m block height into water 3.66 m deep. Dependent measures were maximum head depth, head speed at maximum head depth, and distance from the starting wall at maximum head depth. Statistical analyses yielded significant main effects ($p < 0.05$) for both start type and swimmer experience. Starts executed by the *more experienced* swimmers were deeper and faster than those executed by the *less experienced* swimmers. When asked to dive shallowly, maximum head depth decreased (0.19 m) and head speed increased (0.33 ms^{-1}) regardless of experience. The ability of all swimmers to modify start depth implies that spinal cord injuries during competitive swimming starts are not necessarily due to an inherent inability to control the depth of the start.

Reports from high school and collegiate sports suggest that in competitive swimming, most catastrophic injuries occur when swimmers are performing competitive racing starts (Mueller & Cantu, 2007). As swimming participation in this country continues to remain at high levels (286,147 USA Swimming registered athletes; USA Swimming, 2009) and new facilities are built, there is an obvious need to review all aspects of safety within the sport so as to ensure that rules and regulations are based upon sound safety practices. Since the racing start appears to be the aspect of the sport that is the most inherently risky, it seems critical to carefully examine the variables pertaining to the racing start as a means of identifying the level of risk these variables represent. A review of the existent literature would suggest that this has not been done to any great extent.

The primary concern in this study relates to the interplay among swimmer experience, water depth, head depth, and head speed during the execution of a racing start. Swimmers travel at speeds of approximately 4.0 ms^{-1} when initially

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entering the water. Thus, in shallow water (1 to 2 m) the margin of error is small. Typically, the swimmer's trajectory is such that there is less than a second between the time the hands first hit the water and the time the head reaches its maximum depth (DeMers, 1994). The ability of the swimmer to control his or her trajectory during this phase of the start is a primary determinant as to whether or not the swimmer contacts the bottom. In this paper, we examined the degree to which swimmers' experience allowed them to alter starting depth. Logically, more experienced swimmers should be better able to control the depth of their starts than less experienced swimmers. In one of the few studies reporting head depth following the initiation of a competitive start, Blitvich, McElroy, Blanksby, Clothier, and Pearson (2000) found that elite junior swimmers completed significantly shallower starts in a 1.2 m depth pool than in a 2.0 m depth pool. This occurred without instruction and only information pertaining to water depth was provided. This was a particularly relevant finding because it demonstrated that experienced swimmers were capable of modifying head depth following a competitive start when presented with different starting end water depths. Again, it was important to note that the swimmers were not given any instruction as to the depth of their start; they were simply informed that the depths of the starting ends differed and they were allowed to warm up in these depths prior to executing racing starts. Whether or not swimmers with less skill and/or less competitive experience can also modify start depths was not addressed.

Previous research from our laboratory has shown that swimmers in the older competitive categories and swimmers in the younger age groups differ when the depths of their starts are compared (Cornett, White, Wright, Willmott, & Stager, 2010; Cornett, White, Wright, Willmott, & Stager, 2011a). Older (and presumably larger) swimmers executed deeper starts than younger swimmers regardless of the water depth. And, important to this discussion, during competition swimmers executed shallower starts in shallower water (Cornett et al., 2011a) essentially verifying the findings of Blitvitch et al. (2000). Finally, experienced swimmers asked to complete racing starts into three water depths (1.53 m, 2.14 m, and 3.66 m) executed the deepest starts in the deepest water (Cornett, White, Wright, Willmott, & Stager, 2011b). The evidence presented by these studies suggests that swimmers can and do make adjustments to start depth depending upon the water depth of the pool. They appear to make these decisions about start depth as a function of their experience and prior knowledge of the water depth.

The purpose of this study was to expand upon our initial research line of inquiry (Cornett et al., 2011a, 2011b) and the report by Blitvich et al. (2000) by determining whether or not competitive swimmers could alter *upon request* their maximum depth during the execution of a competitive swimming start. Whereas Cornett et al. (2011a, 2011b) and Blitvich et al. (2000) changed the pool depth and kept constant the instructions given to the swimmers, the current study kept the pool depth constant and changed the instructions given to the swimmers. A secondary purpose was to compare the ability of swimmers with two different experience levels to modify head depth when asked to execute a "shallow" start. Most important in this regard was examining the ability of the swimmers with less competitive experience to control the depth of their starts.

Method

Participants

Two groups of swimmers participated in this study. A group of *more experienced* swimmers (n = 12) was recruited from collegiate swim teams, while a second group of *less experienced* swimmers (n = 13; first year of competitive swimming) was recruited from a local high school junior varsity team. The relevant research questions involved an independent variable (request to dive shallow) that was a repeated measures factor. No attempt was made to control for sex, age, height, or mass between the experience levels. Participant characteristics for the two groups are displayed in Table 1. Prior to the initiation of the study, the project was approved by the university's Human Subjects Committee, and informed consent was obtained from each participant or his/her guardian (when younger than 18 years).

Procedures

The testing took place in a competitive swim venue (22.86 m × 13.70 m) with six lanes and a separate diving well (12.83 m × 10.96 m). No other activity took place in the facility during testing. The diving well depth was 3.66 m (12 ft) in the location that the swimmers executed their starts. A portable starting block with a standard platform height of 0.76 m above the water surface was custom-designed and specifically built for this project (Adolph Kiefer and Associates, Zion, IL). The block was mounted on a steel platform that provided the ability to easily move the starting block to any location desired. The start platform was inclined at an angle of 10° from horizontal and had a surface area of 0.39 m^2.

All swimmers performed two competitive starts from the standard block. For the first start, swimmers were asked to complete a racing start and a subsequent freestyle sprint across the diving well (routine). For the second start, however, the swimmers were requested to execute a shallow start followed by a freestyle sprint across the diving well (requested shallow). Participants mimicked a competitive situation and were asked to step onto the block, to take their mark, and then the start was initiated with an audio signal from a starting system (Daktronics, Omnisport HS 100, Brookings, SD).

Video Recording

The underwater portion of the dive start was filmed using a Canon GL2 digital video camcorder (Canon Inc., Tokyo, Japan) enclosed in a sealed housing unit (Ikelite Underwater Systems, Indianapolis, IN) and mounted on a heavy tripod (Hercules

Table 1 Subject Characteristics

Group	N	Age (yr)	Mass (kg)	Height (m)
Less experienced	13 (10-female, 3-male)	14.8 ± 1.1	57.1 ± 6.2	1.68 ± 0.06
More experienced	12 (5-female, 7-male)	20.1 ± 1.2	73.6 ± 9.3	1.79 ± 0.08

Values are means ± SD for age (yr), mass (kg), and height (m).

model, Quick-Set Inc., Northbrook, IL) on the bottom of the diving well. The camera was aligned perpendicular to the direction of the dive, and a Canon WD-58 wide-angle adapter (Canon Inc., Tokyo, Japan) was used to ensure that the field of view included the subjects' underwater motions from entry until farther than the deepest point of the dive. Camera zoom and focus were adjusted underwater once the tripod/camera unit was in place. An Opticis Optical IEEE1394 FireWire Repeater (M4-100; Opticis North America, Inc., Chatham, Ontario, Canada) extended the range of the video cable to 30 m and enabled the video signal to be input directly to a Gateway (model #: M675, Gateway Inc., Irvine, CA) laptop computer at the poolside. The video signal was captured using SIMI Motion software (zFlo Inc., Quincy, MA).

Calibration

The dive area in front of each block location was calibrated using the 2D direct linear transformation (DLT) procedure in SIMI Motion. A custom-built 1 m × 3 m aluminum frame was placed vertically in line with the center of the starting block, perpendicular to the side of the pool, and with the top of the frame about 0.1 m below the surface of the water. The frame was painted black and 30 bright yellow spheres (marker balls), approximately 0.05 m in diameter, were located at regular intervals around it.

A number of additional cues were included in the same image as the calibration frame: two points on the wall/block, a vertical plumb line with three marker balls, and three further marker balls floating at the water surface. These were used in the rotation and translation of the calibration frame coordinate system to give a pool-based coordinate system in which the kinematic data would be expressed. The origin of the latter system was at water level directly below the center of the starting block, and the axes were oriented such that the x-axis pointed horizontally and perpendicular to the wall and the y-axis pointed vertically upward.

Video Analysis

Following the calibration of the dive area, the competitive dives were recorded and analyzed using SIMI Motion. In each dive, the center of the subject's head was manually digitized from the frame in which it was first visible below the surface through to 10 frames after the instant at which qualitative analysis of the video suggested that the head had reached its maximal depth and was beginning to move back toward the surface. The (x,y) position was calculated using SIMI Motion and the coordinate system transformation described above. Along with the maximum head depth reached in each trial, the speed of the head at this instant and the distance of the head from the wall were determined.

Data Analysis

Two-way (2 × 2) mixed design ANOVAs for experience and instruction with repeated measures on the second (instructional) factor was utilized to test for differences for all three dependent measures (maximum depth of the center of the head, head speed at maximum head depth, and distance from the wall at maximum head depth). When the ANOVA test revealed significant interactions, simple effects analyses were conducted using methods previously established (Keppel & Wickens, 2004). For all analyses reported below, an alpha level of 0.05 was used to determine statistical significance.

Results

The results for the two start types for both experience levels are shown in Table 2. The two-way (2 × 2) mixed design ANOVAs for maximum depth of the center of the head, head speed at maximum head depth, and distance from the wall at maximum head depth yielded significant main effects for instruction: $F(1, 23) = 28.01$, $p < 0.001$, partial $\eta^2 = 0.55$; $F(1, 23) = 10.64$, $p = 0.003$, partial $\eta^2 = 0.32$; $F(1, 23) = 40.33$, $p < 0.001$, partial $\eta^2 = 0.64$, respectively, and experience: $F(1,23) = 29.68$, $p < 0.001$, partial $\eta^2 = 0.56$; $F(1, 23) = 56.37$, $p < 0.001$, partial $\eta^2 = 0.71$; $F(1,23) = 14.48$, $p = 0.001$, partial $\eta^2 = 0.39$, respectively. The significant main effect for instruction indicated that when asked to execute a shallow start, swimmers performed starts that had significantly shallower maximum depths of the center of the head (Figure 1), faster head speeds at maximum head depth (Figure 2), and shorter distances at maximum head depth (Figure 3). The significant main effect for experience indicated that *more experienced* swimmers completed starts that had deeper maximum head depths (Figure 1), faster head speeds at maximum head depth (Figure 2), and greater distances at maximum head depth than their *less experienced* counterparts (Figure 3). There was no significant interaction ($p > 0.05$) for maximum head depth, which indicated that the *less experienced* and *more experienced* swimmers did not differ in their ability to modify maximum head depth when instructed.

Discussion

The purpose of this study was to extend the literature pertaining to the safety of competitive racing starts (Cornett et al., 2011a, 2011b; Blitvich et al., 2000) by examining the ability of competitive swimmers to modify start depth upon request. From the perspective of personal safety, the ability to control start depth is an obvious indication of the motor skills of the swimmer while executing a complex and potential risky

Table 2 Maximum Depth of the Center of the Head (m), Head Speed at Maximum Head Depth (ms^{-1}), and Distance From the Wall at Maximum Head Depth (m)

Group	Requested to Dive Shallow?	N	Maximum Depth of the Center of the Head	Head Speed at Maximum Head Depth	Distance from the Wall at Maximum Head Depth
Less experienced	No	13	0.63 ± 0.19	1.79 ± 0.37	4.66 ± 0.80
	Yes	13	0.48 ± 0.19	2.18 ± 0.46	4.04 ± 0.72
More experienced	No	12	1.03 ± 0.23	2.94 ± 0.45	5.65 ± 0.58
	Yes	12	0.79 ± 0.12	3.20 ± 0.47	4.90 ± 0.51

Note. Values are means ± standard deviation. All values are measured at the center of the head.

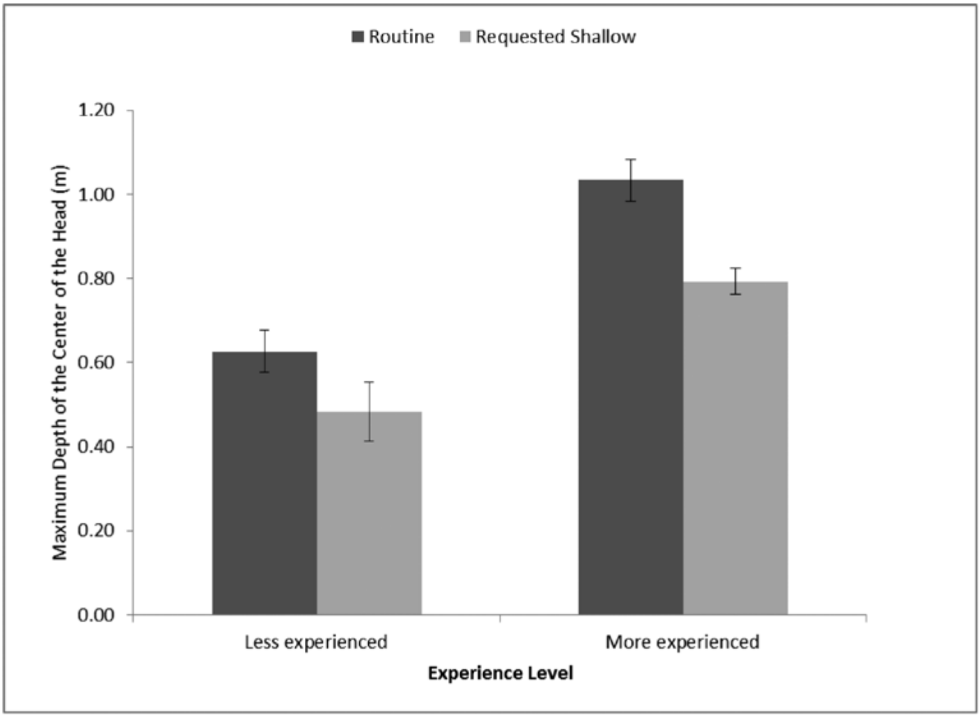

Figure 1— Maximum depth of the center of the head (m) as a function of start type and experience level. There were significant main effects for start type and experience level ($p < 0.05$) indicating that depth was greater for routine starts than requested shallow starts and for more experienced swimmers than less experienced swimmers. Error bars are 1 SE.

ballistic movement. The most important finding was that all swimmers in the study, regardless of the extent of their competitive experience, were able to modify maximum head depth. The lack of a significant interaction between experience and instruction was unexpected. Also, the fact that *more experienced* swimmers did deeper racing starts suggested that they may be at greater risk than *less experienced* swimmers to suffer a catastrophic spinal cord injury during a racing start.

Start Type (Routine vs. Requested Shallow)

Head Depth Modification. To our knowledge, this study is the first to examine the ability of competitive swimmers to modify maximum head depth in response to a request to start shallow. While other studies have inspected swimmers' depth modifications (Blitvich et al., 2000; Cornett et al., 2011a; Cornett et al., 2011b), these prior studies have assessed changes in maximum head depth as a function of differing pool depth. Although the manipulated or independent variable was different between our current study and the earlier reports in the literature, the end result was the same: swimmers displayed the necessary skill to decrease maximum head depth when and where appropriate.

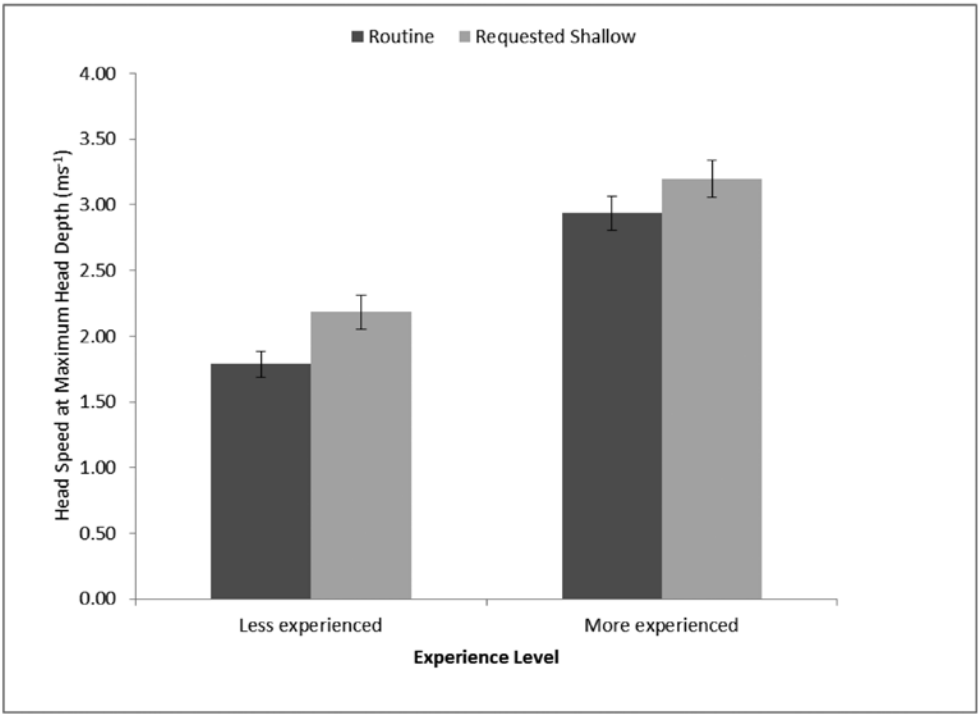

Figure 2 — Head speed at maximum head depth (ms^{-1}) as a function of start type and experience level. There were significant main effects for start type and experience level ($p < 0.05$) indicating that speed was greater for requested shallow starts than routine starts and for more experienced swimmers than less experienced swimmers. Error bars are 1 SE.

In the first such study, Blitvich et al. (2000) compared the maximum head depths of 36 elite junior swimmers following the execution of a racing start into pool depths of 1.2 m and 2.0 m. Maximum head depths differed by 9 cm with shallower starts occurring in the shallower water depth (1.2 m pool depth, 0.79 m; 2.0 m pool depth, 0.88 m). A decrease in maximum head depth was also reported in the present study; however, this decrease was in response to a request to execute a shallower start and the decrease of 19 cm was more than twice the difference reported by Blitvich et al.

In a subsequent study, 11 collegiate swimmers were asked to complete three racing starts into pools with three different depths: 1.53 m, 2.14 m, and 3.66 m (Cornett et al., 2011b). The results were similar to Blitvich et al. (2000) in that shallower starts were performed in the shallower pools; maximum head depth was 17 cm shallower in the 1.53 m pool than the 3.66 m pool and 15 cm shallower in the 2.14 m pool than the 3.66 m pool. The magnitude of the depth modifications in the Cornett et al. study corresponded closely with those in the present analysis.

Finally, Cornett et al. (2011a) compared the maximum head depths of racing starts performed while in competition in two different water depths (1.22 m and

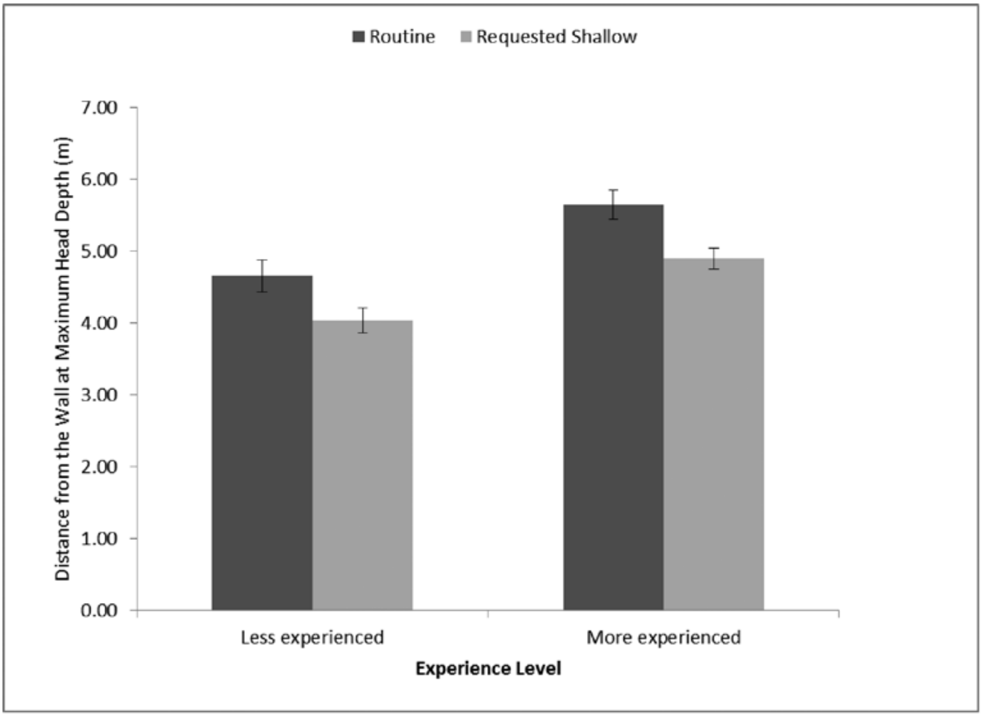

Figure 3 — Distance of the center of the head from the wall at maximum head depth (m) as a function of start type and experience level. There were significant main effects for start type and experience level ($p < 0.05$) indicating that distance from the wall was greater for routine starts than requested shallow starts and for more experienced swimmers than less experienced swimmers. Error bars are 1 SE.

2.29 m). The starts used in the analysis matched swimmers for age, stroke, and sex. Maximum head depth was significantly shallower for competition starts in the 1.22 m water depth than for starts in the 2.29 m water depth (0.53 m vs. 0.70 m for freestyle starts, respectively; Cornett et al., 2011a). Once again, the magnitude of the difference in maximum head depth (17 cm) corresponded closely to the value observed in the present analysis, despite the aforementioned differences in the independent variables. The results of the current and previous research, however, suggested that competitive swimmers do have the capability to modify head depth when they are requested to do so or when they have prior knowledge of the pool depth.

Head Speed With Depth Modification. The four studies discussed above all found significant differences in maximum head depth in response to differences in pool depth (Blitvich et al., 2000; Cornett et al., 2011a, 2011b) or to a request to dive shallow (the current report). While these depth modifications are interesting and relevant, perhaps as important (from the perspective of safety) is the manner in which head speed at maximum head depth and distance from the wall at maximum head depth relate to maximum head depth.

We report a significant increase in head speed at maximum head depth (0.33 ms^{-1}) when swimmers were asked to perform a shallow start. The explanation for this is that swimmers presumably travel through less water both vertically and horizontally while executing a shallower start and therefore lose less momentum due to the lower drag forces of the water on the body. Cornett et al. (2011a) reported a similar finding in their comparison of competitive racing starts in two water depths. Head speed at maximum head depth for starts in 1.22 m (3.08 ms^{-1}) were significantly faster than for starts in 2.29 m (2.77 ms^{-1}) for swimmers 15 years and older competing in freestyle events (Cornett et al., 2011a). Again, these swimmers' starts resulted in faster head speeds but these faster speeds occurred at shallower maximum head depths.

In contrast to the current report and Cornett et al. (2011a), neither Blitvich et al. (2000) nor Cornett et al. (2011b) detected differences in head speed at maximum head depth in different pool depths despite finding significantly shallower maximum head depths in shallower pools. The reason for the discrepant findings is unclear. The differences in head depth were also small in both reports and the lack of significance may have been due to low statistical power to detect differences. From the perspective of safety, the small differences (or similarities) in head speed are perhaps irrelevant in that all head speeds reported in these studies exceed the proposed thresholds (Blanksby, Wearne, & Elliott, 1996) resulting in severe head and/or neck trauma should an impact with a solid surface occur. From the perspective of swim performance, none of these studies examined the time to a measured distance (e.g., 10 or 12 meters from the start wall) and thus little can be concluded about the advantage or disadvantage of a faster head speed and a shallower maximum head depth. Additional data need to be analyzed to provide better interpretation of these relationships.

Head Distance With Depth Modification. Distance from the wall at maximum head depth significantly decreased (from 5.13 m to 4.45 m) when swimmers where asked to complete a shallow start. We again suggest that this is a logical outcome of a shallower start because the swimmer reaches maximum head depth faster and thus does not have as much time to move horizontally. Blitvich et al. (2000) and Cornett et al. (2011a) also found shallower starts to be consistent with shorter distances at maximum head depth. Blitvich et al. reported shorter distance from the wall at maximum head depth to be in a 1.2 m pool (4.72 m) than in a 2.0 m pool (5.01 m). Similarly, Cornett et al. (2011a) reported significantly different values for distance from the wall at maximum head depth between starts in a 1.22 m pool (4.26 m) and a 2.29 m pool (4.60 m). Like the results from the current study, the changes in distance from the wall were associated with decreases in maximum head depth. Cornett et al. (2011b), however, did not find differences in distance from the wall at maximum depth between any of the three pool depths utilized.

The Relationships Among Head Depth, Head Speed, and Distance. The differences between the starting conditions in maximum head depth, head speed at maximum head depth, and distance from the wall at maximum head depth were correlated such that as maximum head depth decreased distance from the wall decreased ($r = 0.71$, $p < 0.001$) and head speed at maximum head depth increased ($r = –0.43$, $p = 0.034$). Thus, shallower starts are consistent with shorter distances from the wall at maximum head depth and greater head speed at maximum head depth. As mentioned earlier, additional attention needs to be focused upon these relationships perhaps as a means to provide coaches and swimmers with information pertaining to the implications of this research on swim performance. If, for example, it can be demonstrated that there is little to no advantage for swimmers to attain deep start depths from the performance perspective, it may change the way in which coaches instruct and teach swimmers to perform starts.

Experience

The *more experienced* competitive swimmers attained deeper maximum depths of the center of the head, greater head speeds at maximum head depth, and farther distances from the wall at maximum head depth after completing a racing start than their *less experienced* counterparts. The greater age, mass, and height of the more experienced group (all statistically significant, $p < 0.01$) confounds the statistical analysis of differences due to experience alone. Additionally, the *more* and *less experienced* groups differed with respect to the percentage of males and females. We determined that it is unlikely that sex differences confounded the analysis of experience as there was not a significant difference ($p > 0.05$) between the sexes for maximum depth of the center of the head or distance from the wall at maximum head depth. While there was a significant difference between males and females for head speed at maximum head depth, analysis of covariance revealed that the *more experienced* group had significantly greater head speed that the *less experienced* group when controlling for sex. We have previously suggested that the intention of the athlete is a major determinant of maximum head depth, while the head speed at maximum head depth is likely a function of the size and experience of the athlete (Cornett et al., 2011a). In order to investigate this hypothesis, partial correlations were performed on the data which enabled us to look at the relationship between experience and maximum depth of the center of the head, head speed at maximum head depth, and distance from the wall at maximum head depth while controlling for the effects of age, height, and mass. Experience and head speed at maximum head depth were significantly related ($r = 0.64$, $p = 0.01$) while controlling for age, height, and mass. Experience, then, accounts for a significant portion (41%) of the variation in head speed at maximum head depth. The most likely explanation for this finding is that experienced swimmers had "cleaner," more streamlined entries and were able to maintain more momentum through the air-water interface.

The partial correlation between experience and maximum head depth ($r = 0.10$, $p = 0.667$) was not significant when controlling for age, height, and mass. This is in agreement with our hypothesis that the athlete's intent supersedes other factors such as experience and mass in determining maximum depth of the center of the head (Cornett et al., 2010). Bearing in mind that correlation should not imply causation, we must consider alternative possibilities. Additional analyses revealed a significant partial correlation between maximum head depth and height ($r = 0.44$, $p = 0.040$) while controlling for age, experience, and mass and between maximum head depth and age ($r = -0.55$, $p = 0.008$) while controlling for height, experience, and mass. The unique, common variance between maximum head depth and height and maximum head depth and age suggest that multiple factors are involved in determining the maximum depths attained by competitive swimmers performing

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racing starts. More research is needed in order to determine which factors are most important in determining maximum start depth.

Pool Safety

While it is true that *less experienced* swimmers (as a group) and *more experienced* swimmers (as a group) were not different in the extent to which they were able to modify maximum head depth during a competitive start, it is important to note that not all of the *less experienced* swimmers did so. While 100% of the *more experienced* swimmers completed shallower starts upon request three out of 13 *less experienced* swimmers did not. Because it appears that the latter's ability to control start depth is not certain, increased caution is required when *less experienced* swimmers are competing and diving into shallow water. The point is that *less experienced* swimmers cannot be relied upon with similar certainty to *more experienced* swimmers to be able to control depth despite the finding that statistically, "requested shallow" starts were shallower for both groups. These findings support the recent USA Swimming requirement that coaches personally evaluate all novice swimmers as far as their ability to control start depth before allowing them to use starting blocks during competition. Additional observations are needed to establish the reliability of swimmers of varying abilities to control depth following a racing start.

Conclusions

The aim of this study was to investigate the ability of competitive swimmers with two contrasting experience levels to modify the maximum depth of the center of the head upon request during the execution of a competitive swim start. Our results demonstrated that, regardless of ability level, when asked to employ a shallower start, competitive swimmers decreased the depth that their heads reach during a racing start. This maximum depth was reached closer to the start wall and with a greater head speed than when no request to dive shallow was given. These findings complement prior research that concluded swimmers modify start depth when competing in different water depths. In the present study, however, not all of the *less experienced* swimmers could be relied upon to modify their starts despite the statistically significant differences observed between the two start types. Thus, we conclude that the *less experienced* athletes are less predictable and more variable in terms of the outcome of their starts (controlling depth) than are the *more experienced* athletes. It may be that careful observation and specific dedicated practice of this skill in deeper water is needed before *less experienced* swimmers should be permitted to execute competitive racing starts in shallow water.

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References

Blanksby, B.A., Wearne, F.K., & Elliott, B.C. (1996). Safe depths for teaching children to dive. *The Australian Journal of Science and Medicine in Sport, 28*(3), 79-85.

Blitvich J.D., McElroy, G.K., Blanksby, B.A., & Douglas, G.A. (1999). Characteristics of 'low risk' and 'high risk' dives by young adults: Risk reduction in spinal injuries. *Spinal Cord, 37*(8), 553-559.

Blitvich J.D., McElroy, G.K., Blanksby, B.A., Clothier, P.J., and Pearson, C.T. (2000). Dive depth and water depth in competitive swim starts. *Journal of Swimming Research, 14*, 33-39.

Cornett, A.C., White, J.C., Wright, B.V., Willmott, A.P., & Stager, J.M. (2010). Racing start safety: Head depth and head speed during competitive swim starts into a water depth of 1.22 m. *International Journal of Aquatic Research and Education, 4*, 365-378.

Cornett, A.C., White, J.C., Wright, B.V., Willmott, A.P., & Stager, J.M. (2011a). Racing start safety: Head depth and head speed during competitive swim starts into a water depth of 2.29 m. *International Journal of Aquatic Research and Education, 5,* 14-31.

Cornett, A.C., White, J.C., Wright, B.V., Willmott, A.P., & Stager, J.M. (2011). Water depth influences the head depth of competitive racing starts. *International Journal of Aquatic Research and Education, 5*, 32-41.

DeMers, G. (1994). To dive or not to dive: What depth is safe? *Journal of Physical Education, Recreation, and Dance,* 17-22.

Keppel, G., & Wickens, T.D. (2004). *Design and analysis: A researcher's handbook*. (4th ed.). Upper Saddle River, NJ: Pearson Prentice Hall.

Mueller, F.O., & Cantu R.C. (2007). *Catastrophic sports injury research*. Twenty-Fifth Annual Report: Fall 1982 to Spring 2007. University of North Carolina at Chapel Hill, National Center for Catastrophic Injury Research.

USA Swimming. (2009). *2009 Membership Demographics.* Colorado Springs, CO: Author.

Welch, J., & Owens, W. (1986). Water depth requirements of competitive racing starts. *Swimming research, 2*(3), 5-7.