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Andrew C. Cornett

Eastern Michigan University, acornet2@emich.edu

Hiroki Naganobori

Indiana University

Joel M. Stager

Indiana University

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Intra-Individual Head Depth Variability During the Competitive Swim Start

Andrew C. Cornett, Hiroki Naganobori, and Joel M. Stager

The research on the competitive swim start primarily consists of group mean and maximum depths with little attention given to individual variability. The purpose of this study was to quantify intra-individual racing start depth variability and use it to assess minimum water depth standards. Twenty-two competitive swimmers executed five racing starts into a water depth of 3.66 m. Intra-individual variability was quantified by taking the standard deviation of the maximum depth of the center of the head for the five racing starts executed by each swimmer. The mean value was 0.09 m with a standard deviation of 0.06 m. Analysis of means and standard deviations showed that about one-third of swimmers would be expected to have a head depth deeper than the current minimum water depth requirement (i.e., 1.22 m) for at least 10% of starts. Based on this research conducted in deep water, our recommendation is that swimmers demonstrate both consistency and control of racing start depth before being permitted to execute starts in shallow water.

Most competitive swimming races begin with the swimmers diving into the water from a starting platform elevated above the water surface. The potential for injury exists during the execution of this complex motor task if an athlete contacts the pool bottom due to a dive that is too deep and/or a pool that is too shallow. When a swimmer comes into contact with the pool bottom during the start, the risk and severity of injury is influenced by many factors such as (a) the swimmer's momentum; (b) the swimmer's age and physical traits; (c) the orientation of the head, neck, and torso; and (d) the location of impact and interface (Viano & Parenteau, 2008). Depending on the factors above, injuries may be as minor as bumps, scrapes, or bruises and as severe as cervical vertebrae fractures or dislocations.

In an effort to prevent all such injuries from occurring during the execution of racing starts, governing bodies in the sport mandate the minimum water depth at the starting end of competitive swim pools. In the United States, for example, USA Swimming (USAS), the National Federation of State High School Associations (NFHS), and the National Collegiate Athletic Association (NCAA) require a minimum water depth of 1.22 m (4 ft) in order for swimmers to execute competitive racing starts from a starting block (USA Swimming, 2012; National Federation of

Andrew Cornett is an assistant professor at Eastern Michigan University, School of Health Promotion and Human Performance, Ypsilanti, MI. Hiroki Naganobori is at Indiana University in Bloomington. Joel Stager is the Director of the Counsilman Center for the Science of Swimming at Indiana University in Bloomington, IN, where the research was conducted.

State High School Associations, 2012; NCAA, 2011). The fact that all three of the governing bodies in the United States have the same minimum water depth might suggest that empirical evidence points toward this particular depth, but the extent to which this water depth is supported by data derived through research is unclear.

The current literature on competitive swim start safety predominantly consists of comparisons of group means for racing start depth as a method of stratifying risk. Previous research has examined the effect of start type (Counsilman, Nomura, Endo, & Counsilman, 1988; Gehlsen & Wingfield, 1998; Welch & Owens, 1986), swimmer age (Cornett, White, Wright, Willmott, & Stager, 2010, 2011a, 2011b), swimmer experience level (White, Cornett, Wright, Willmott, & Stager, 2011), the competitive stroke performed during the first length of competition (Cornett et al., 2010, 2011a, 2011c), and pool depth (Blitvich, McElroy, Blanksby, Clothier, & Pearson, 2000; Cornett et al., 2011b). Broad conclusions from this research are that (a) older and more experienced swimmers have deeper racing starts than their younger and less experienced counterparts; (b) starts involving steeper entry angles, e.g., the pike entry, result in deeper starts than those utilizing a “flatter” entry type; (c) start depth varies with the competitive stroke performed during the first length of competition with the deepest starts associated with breaststroke and the shallowest with the front crawl, or freestyle; and (d) start depth changes as water depth changes.

There is value in the above research, but when it comes to establishing minimum water depth rules, it seems more appropriate to consider the extreme cases, or maximum depth values, rather than group means. The reason for this is simple: the group mean describes the typical case and the swimmer who contacts the pool bottom during execution of a racing start is not a typical case. Cornett et al. (2010) demonstrated this when they reported that 14 out of 471 (3.0%) swimmers that executed a racing start in a swimming competition in a 1.22 m (4 ft) water depth contacted the pool bottom. A few studies have presented data on the deepest maximum head depth observed in a variety of starting conditions and one study (Gehlsen & Wingfield, 1998) used this maximum value to suggest revisions to the minimum water depth standards. Gehlsen and Wingfield (1998) analyzed the depths and speeds of collegiate swimmers performing different types of starts from a variety of starting block heights and concluded that 1.22 m was not an adequate minimum water depth. Because none of the swimmers attained a head depth deeper than 1.4 m in the study, they recommended that minimum water depth be “greater than 1.4 m for experienced divers” (p. 30).

Using the group maximum depth to establish minimum water depth standards—as Gehlsen and Wingfield (1998) did—is perhaps more appropriate than utilizing group mean depths, but there are issues with this approach as well. The problems might be the inherent assumptions that (a) swimmers dive to the same depth every time they execute a racing start and (b) the swimmer who performs the deepest *observed* racing start is at the greatest relative risk. Our current hypotheses are that (a) there is intra-individual variability associated with racing start depth and (b) a swimmer with high racing start depth variability might be at greater risk of impacting the pool bottom than another swimmer that has a deeper mean racing start depth but lower intra-individual variability (Figure 1). To date, our hypotheses have gone untested because we have been unable to locate any studies that present intra-individual racing start depth variability when the same swimmer executes

multiple racing starts from the same starting block into the same water depth using the same start type.

Thus, the purposes of this study were (a) to quantify intra-individual racing start depth variability when the same swimmer executes multiple starts under the same experimental conditions; (b) to determine whether or not intra-individual racing start depth variability is related to swimmer characteristics such as age, height, mass, and competitive experience as a means of further stratifying relative risk; and (c) to use individual mean and variability values to assess current minimum pool depth regulations.

Method

Participants

The university's Human Subjects Committee approved the project prior to the initiation of the study and informed consent was obtained from each participant and his/her guardian (when younger than 18 years of age). The participants were all members of a competitive swim club in the Midwestern United States. The swimmers' age, height, mass, and competitive swimming experience were recorded prior to data collection. Because a focus of the study was to determine which factors, if any, were related to racing start depth variability during the competitive racing start, a wide range for age, height, mass, and competitive swimming experience was desirable.

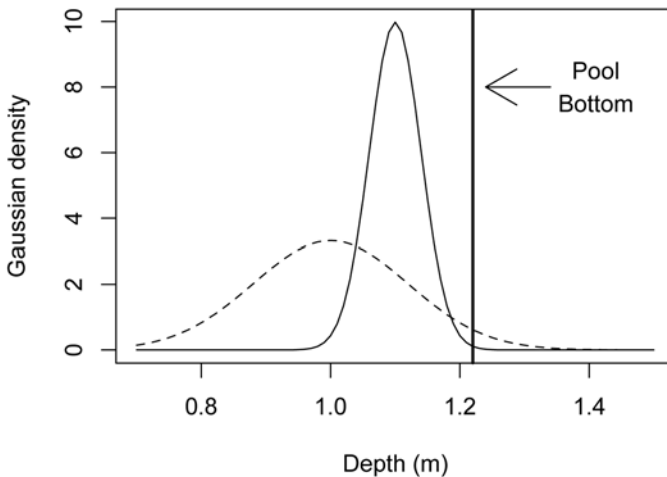


Figure 1 — The racing start depth distribution for swimmer A (solid line) has a deeper mean starting depth but lower variability than the distribution for swimmer B (dashed line). In this hypothetical situation, the probability that swimmer B will contact the pool bottom in a 1.22 m pool is greater than for swimmer A.

Procedures

The testing took place in a swimming venue that consisted of a six-lane competition pool (22.86 m × 13.70 m) and a separate diving well (12.83 m × 10.96 m). Data collection was conducted in the diving well and the water depth was 3.66 m (12 ft) where the swimmers entered the water. No other activity took place in the facility during testing. A portable starting block with a standard platform height of 0.76 m above the water surface was custom designed and built for this project (Adolph Kiefer and Associates, Zion, IL). The block was mounted on a steel platform that provided the ability to move the starting block to various locations on the pool deck. The start platform was inclined at an angle of 10° from horizontal and had a surface area of 0.39 m².

All swimmers performed five competitive starts from the standard starting platform into the diving well. For all starts, swimmers were asked to complete a racing start and a subsequent front crawl, or freestyle, sprint across the diving well. In order to mimic a typical competitive situation, swimmers were asked to step onto the block, to take their mark, and then the start was initiated with an audio signal from a commercial starting system (Daktronics, Omnisport HS 100, Brookings, SD).

Video Recording, Calibration, and Video Analysis

The video recording, calibration, and video analysis procedures have been previously described (Cornett et al., 2011c). Briefly, 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 tripod on the bottom of the diving well. 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. The video signal was captured using SIMI Motion software (zFlo Inc., Quincy, MA).

The dive area in front of each block location was calibrated using 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 origin of the coordinate 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.

Following the calibration of the dive area, the competitive dives were recorded and analyzed using SIMI Motion. In each dive, the external auditory meatus, an anatomical landmark for the center of the subject's head, was manually digitized beginning with the frame in which it was first visible. For more detail on the procedures, see Cornett et al. (2011c).

Data Analysis

The maximum depth of the center of the head (DEPTH; meters) was determined for each trial. Intra-individual racing start depth variability was quantified in this study by taking the standard deviation of the maximum depth of the center of the head for the five racing starts executed by each swimmer (SD_DEPTH; meters). Pearson

product moment correlation coefficients were computed between SD_DEPTH and five variables: (a) age (AGE; years), (b) height (HEIGHT; meters), (c) mass (MASS; kilograms), (d) competitive swimming experience (EXPERIENCE; years), and (e) the mean value for the maximum depth of the center of the head for the five racing starts executed by each swimmer (MEAN_DEPTH; meters). All calculations and analyses were performed using IBM SPSS Statistics (Version 19.0; IBM, Armonk, NY), and an alpha level of 0.05 was used to determine statistical significance for all inferential procedures.

In order to assess current minimum water depth standards, we first made an assumption that DEPTH was normally distributed for each swimmer. An inspection of normal probability plots for DEPTH for the five racing starts executed by each swimmer indicated that this assumption was justified. Then, 0.15 m was added to the MEAN_DEPTH for each swimmer to create an adjusted head depth variable (ADJUSTED_MEAN_DEPTH) because the external auditory meatus, the landmark for the center of the head, is approximately 0.15 m shallower than the deepest point of the head (Blitvich et al., 2000). Once this adjustment was made, we used ADJUSTED_MEAN_DEPTH and SD_DEPTH to determine the expected percentage of starts for each swimmer deeper than 1.22 m. This depth was of particular interest because it is the current minimum water depth in which swimmers are allowed to execute racing starts in the United States (USA Swimming, 2012; National Federation of State High School Associations, 2012; NCAA, 2012). We calculated the expected percentage of starts deeper than 1.22 m for each swimmer by first calculating a z score using the following equation:

$$z = \frac{X - \bar{X}}{s}$$

where X was set to 1.22 m for each swimmer, \bar{X} was the ADJUSTED_MEAN_DEPTH, and s was SD_DEPTH. Next, the area under the curve beyond each z score was determined using the Gaussian, or Normal, distribution and that value was used as the estimated percentage of starts deeper than 1.22 m for each swimmer. A sample calculation with an ADJUSTED_MEAN_DEPTH of 1.15 m and SD_DEPTH of 0.05 m is shown in Figure 2.

Results

Twenty-two swimmers were recruited to participate in this study and the means and standard deviations for AGE, HEIGHT, MASS, and EXPERIENCE were 17.1 ± 4.4 years, 168.6 ± 12.5 cm, 65.6 ± 16.3 kg, and 6.5 ± 4.9 years, respectively. MEAN_DEPTH, ADJUSTED_MEAN_DEPTH, and SD_DEPTH for each subject are shown in Table 1. One of the swimmers was identified as an outlier because the standardized score, or z score, for SD_DEPTH for the swimmer ($\frac{0.29 - 0.09}{0.06} = 3.33$) was greater than 3.29, which has been previously identified as a cutoff for univariate outliers (Tabachnick & Fidell, 2007). As a result, this swimmer was excluded from the data set during the correlational analysis but was included in the assessment of pool depth regulations.

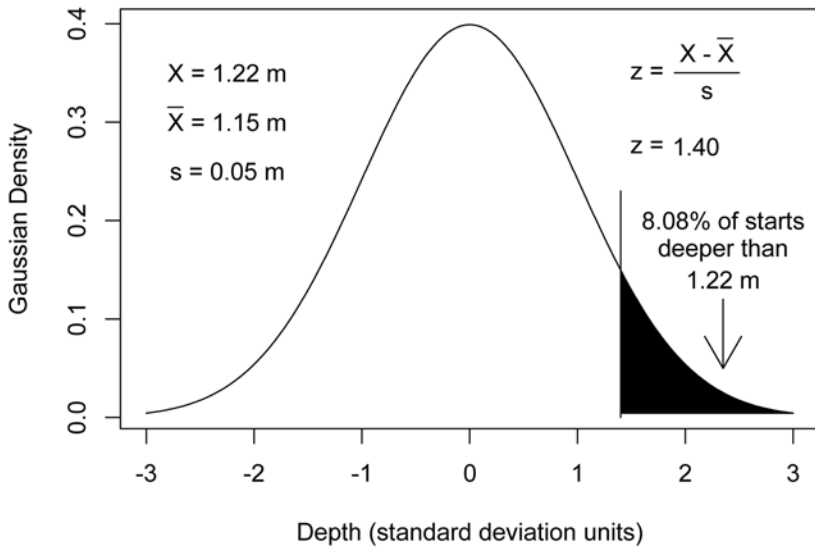


Figure 2 — Sample calculation for the estimated percentage of starts deeper than 1.22 m for each swimmer where X is the depth of interest, \bar{X} is the mean value for the maximum depth of the center of the head from five racing starts with a 0.15 m adjustment added to it to estimate the actual deepest point of the head, s is the standard deviation for the maximum depth of the center of the head from five racing starts, and z is the z score. The area shaded in black is the area under the curve beyond a z score of 1.40 and corresponds to 8.08% of starts deeper than 1.22 m for this swimmer.

Pearson correlation coefficients revealed that SD_DEPTH was significantly correlated with $MEAN_DEPTH$ ($r = 0.66$, $p = 0.001$) but not with any of the subject characteristics (i.e., AGE , $HEIGHT$, $MASS$, and $EXPERIENCE$; $p > .05$).

Finally, when using $ADJUSTED_MEAN_DEPTH$ and SD_DEPTH to assess pool depth regulations for racing starts, the z scores for the swimmers for a depth of 1.22 m ranged from -2.29 to 17.00 . The percentage of starts estimated to be deeper than 1.22 m for each swimmer—determined using the z scores and the Gaussian, or Normal, distribution—ranged from less than 0.01% to 98.90% (Table 1).

Discussion

Due to the potentially catastrophic nature of injuries resulting from swimmers contacting the pool bottom when executing a racing start, it seems that minimum water depth rules need to be reinforced by empirical data. The competitive swim start safety literature primarily consists of reports of mean and maximum depths for particular groups or experimental conditions. The present study suggests that swimmers have unique distributions for racing start depth and, as a result, individual

Table 1 Means, Standard Deviations, z Scores, and Percentage of Starts Deeper Than 1.22 m for the Five Racing Starts Executed by Each Swimmer

Subject	MEAN_DEPTH	ADJUSTED_MEAN_DEPTH	SD_DEPTH	z Score for 1.22 m	% of Starts Deeper Than 1.22 m
1	1.55	1.70	0.21	-2.29	98.90
2	1.20	1.35	0.18	-0.72	76.42
3	1.01	1.16	0.09	0.67	25.14
4	0.96	1.11	0.12	0.92	17.88
5	0.79	0.94	0.29	0.97	16.60
6	0.98	1.13	0.08	1.13	12.92
7	1.02	1.17	0.04	1.25	10.56
8	0.95	1.10	0.09	1.33	9.18
9	1.00	1.15	0.05	1.40	8.08
10	0.93	1.08	0.07	2.00	2.28
11	0.86	1.01	0.10	2.10	1.79
12	0.86	1.01	0.09	2.33	0.99

(continued)

Table 1 (continued)

Subject	MEAN_DEPTH	ADJUSTED_MEAN_DEPTH	SD_DEPTH	z Score for 1.22 m	% of Starts Deeper Than 1.22 m
13	0.91	1.06	0.05	3.20	0.07
14	0.65	0.80	0.10	4.20	<0.01
15	0.75	0.90	0.06	5.33	<0.01
16	0.78	0.93	0.05	5.80	<0.01
17	0.65	0.80	0.07	6.00	<0.01
18	0.55	0.70	0.08	6.50	<0.01
19	0.55	0.70	0.07	7.43	<0.01
20	0.54	0.69	0.07	7.57	<0.01
21	0.53	0.68	0.05	10.80	<0.01
22	0.73	0.88	0.02	17.00	<0.01

Note. MEAN_DEPTH and SD_DEPTH are the mean and standard deviation for the maximum depth of the center of the head for five racing starts. ADJUSTED_MEAN_DEPTH is the MEAN_DEPTH plus 0.15 m to account for the distance from the center of the head to the deepest part of the head.

variability in racing start depth should be considered, if appropriate, data-driven minimum water depth standards are to be developed.

To briefly review, there were three purposes of this study relating to intra-individual variability: (a) to quantify it; (b) to determine which factors, if any, were correlated with it; and (c) to use it to assess current minimum water depth regulations. The major findings regarding the first two purposes were that (a) the range of values for intra-individual variability is quite large in a competitive sample and (b) intra-individual variability is positively correlated with the average depth of the swimmer's racing start. Two of the relevant results related to the third purpose, the assessment of minimum water depth regulations, were that when executing racing starts in deep water: (a) approximately one-third of swimmers are expected to execute at least 1 in 10 starts deeper than 1.22 m, the current minimum water depth for racing starts, and (b) the deepest part of the head for 2 of the 22 swimmers was, *on average*, deeper than 1.22 m. The results for the three purposes are discussed independently in this section.

Intra-Individual Racing Start Depth Variability

Three racing start safety studies (Councilman et al., 1988; Gehlsen & Wingfield, 1998; Welch & Owens, 1986) asked swimmers to execute two or three racing starts under the same experimental conditions, but these previous studies did not report individual means or standard deviations. Instead, in these early studies, the data were pooled and presented as group means for each starting condition. As a result, they do not provide values to which we can compare our data.

In this regard, the standard deviation for the maximum depth of the center of the head (SD_DEPTH) for the five racing starts executed by the swimmers filmed in the present study had a mean value of 0.09 m, a standard deviation of 0.06 m, and ranged from 0.02 to 0.29 m. The range of values for SD_DEPTH seems large as SD_DEPTH was nearly 15 times greater for the most variable swimmer than for the least variable one. The practical significance of the difference between SD_DEPTH values of 0.02 and 0.29 m can be demonstrated with an example. Although MEAN_DEPTH differed by 6 cm between the two swimmers with the highest and lowest SD_DEPTH values in this study, consider the hypothetical situation if the two swimmers, Swimmer A and Swimmer B, had had the same MEAN_DEPTH value (e.g., 1.0 m) but SD_DEPTH values of 0.02 and 0.29 m, respectively. Assuming that DEPTH is normally distributed for each swimmer, we can use the standard normal distribution to determine the percentage of starts within a range of depths. Swimmer A, with a MEAN_DEPTH of 1.0 m and an SD_DEPTH of 0.02 m, would be expected to have a DEPTH between 0.98 and 1.02 m for about two-thirds of starts and between 0.96 and 1.04 m for approximately 95% of starts. This means that DEPTH for 19 out of 20 starts for Swimmer A would fall within an 8 cm (3.15 in) window. On the other hand, Swimmer B, with the same MEAN_DEPTH of 1.0 m and a SD_DEPTH of 0.29 m, would be expected to have a DEPTH between 0.71 and 1.29 m for about two-thirds of starts and between 0.42 and 1.58 m for approximately 95% of starts. For Swimmer B, then, DEPTH for 19 out of 20 starts would fall within a 1.16 m (45.67 in) window. The range of DEPTH values expected for Swimmer B seems substantial considering that the mandated minimum water depth for racing starts is 1.22 m (USA Swimming, 2012;

National Federation of State High School Associations, 2012; NCAA, 2011). This hypothetical example demonstrates that it is not sufficient to assess swimmer risk during the execution of the racing start by evaluating a single head depth value, or even the average depth to which a swimmer dives; intra-individual racing start depth variability must be considered as well.

Factors Correlated with Intra-Individual Racing Start Depth Variability

Because SD_DEPTH varies from swimmer to swimmer, and variability may be interpreted to add to swimmer risk, it was decided to examine the factors that maybe causal to or coincident with this intra-individual variability. The significant positive correlation between SD_DEPTH and MEAN_DEPTH suggests that intra-individual variability increases as the average depth of the start increases. While we cannot know for certain if a causal relationship exists between these variables, we originally hypothesized that SD_DEPTH would increase with MEAN_DEPTH. We expected this relationship simply because there is more “room” for start depth to vary for swimmers that, on average, dive deeper. Since this study was conducted in a diving well with a water depth of 3.66 m, it would seem that SD_DEPTH was not constrained by the pool bottom. That is, the water was likely deep enough that the pool bottom did not prevent racing start depth from varying in that direction. The same cannot necessarily be said of the water surface though. It seems that the water surface would place a greater constraint on SD_DEPTH for shallower starts than deeper ones. We recognize that this is speculation and recommend that future research replicate the present study in different water depths as a means to confirm or reject this hypothesis.

The significant positive correlation between SD_DEPTH and MEAN_DEPTH is interesting but not necessarily practically useful. MEAN_DEPTH is measured after a swimmer has executed a racing start so it cannot be used to identify the most variable swimmers a priori. Of the subject characteristics that could be measured before the execution of a racing start (i.e., AGE, HEIGHT, MASS, and EXPERIENCE), none were correlated with SD_DEPTH.

Common sense would argue that as swimmers gain competitive swimming experience, racing start depth variability would decrease. Our previous research demonstrated that experienced competitive swimmers perform deeper racing starts than those of inexperienced competitive swimmers (White et al., 2011). Because more experienced swimmers tend to execute deeper starts and racing start depth variability increases with start depth, we hypothesized that a correlation might exist between SD_DEPTH and EXPERIENCE if we controlled for MEAN_DEPTH. However, no relationship was found when we conducted a partial correlation and we can only speculate as to why our hypothesis concerning this relationship proved unconfirmed.

It may be that our original hypothesis differed from the hypothesis we actually tested. We initially expected that as a swimmer accumulated practice time executing racing starts the swimmer’s racing start consistency would improve (as reflected by a decrease in SD_DEPTH). However, we did not measure accumulated racing start practice time; we measured competitive swimming experience. We did this because while it is reasonable to expect swimmers to recall the number of years they have

been involved in competitive swimming, it seemed unlikely that swimmers could precisely estimate the amount of practice time spent on racing starts during the course of their careers. Although we assume that the two variables are correlated, we could find no literature describing the nature of this relationship. Future research should focus on quantifying the amount of daily, weekly, monthly, or seasonal practice time coaches and swimmers specifically dedicate to the racing start.

Assessment of Minimum Water Depth Regulations

This is the first study to use intra-individual variability when assessing racing start depth requirements. The results of this analysis demonstrate that when performing racing starts in relatively deep water (in this study, 3.66 m), competitive swimmers regularly execute starts with head depths close to or greater than 1.22 m, the current minimum water depth requirement. The deepest part of the head for 6 of 22 (27%) swimmers was, on average, within one-tenth of a meter of 1.22 m, which provides a small margin for error. For two of the swimmers in the study, the deepest part of the head was, on average, deeper than 1.22 m. And finally, one-half of the swimmers in the study are expected to have a head depth deeper than 1.22 m in a water depth of 3.66 m for at least 1 in 100 starts. Based on these numbers alone, it seems that 1.22 m is not an appropriate minimum water depth for the execution of competitive swim starts.

There have been two other studies in the literature that assessed minimum water depth requirements by having swimmers execute racing starts in relatively deep water (Gehlsen & Wingfield, 1998; Welch & Owens, 1986). As occurred in the current study, both of these previous studies observed swimmers with head depths deeper than 1.22 m when performing starts in deep water. Welch and Owens (1986) filmed collegiate swimmers executing racing starts from starting blocks of varying heights in a water depth of 3.81 m (12.5 ft). They concluded that minimum water depth should be increased to 1.37 m (4.5 ft) to “provide an increase margin of safety” (p. 6) to the swimmers. Gehlsen and Wingfield (1998) were also interested in the effect of start type (pike and flat) and starting platform height (0.46, 0.56, 0.66, and 0.76 m) on racing start parameters when collegiate swimmers execute racing starts in a water depth of 4 m (13.1 ft). Because of the observation that none of the swimmers “ascended” to a depth greater than 1.4 m, Gehlsen and Wingfield (1998) recommended that pool water depth should be at least 1.4 m for “experience divers.” Based solely on the head depths (and not depth variability) of the swimmers in our study, we would agree with Welch and Owens (1986) and Gehlsen and Wingfield (1998) in that 1.22 m is not an appropriate minimum water depth for the execution of racing starts; however, the maximum head depth value recorded in deep water is not the only factor that requires consideration.

It is important to consider the effect of water depth on racing start depth when evaluating minimum water depth regulations. Blitvich et al. (2000) analyzed the racing start parameters of 36 junior elite swimmers when executing starts in two different water depths: 1.2 m and 2.0 m. They found that mean maximum head depth was significantly deeper in a 2.0 m water depth (0.88 m) than in a 1.2 m water depth (0.79 m). Subsequent studies have confirmed the findings of Blitvich et al. for racing starts in competition (Cornett et al., 2011a) and in different water depths (Cornett et al., 2011d). From their study on the effect of water depth on

racing start depth. Blitvich et al. concluded that minimum water depth requirements “appear safe for use by skilled competitive swimmers” (p. 38) but added that “diving skills instruction should be provided for swimmers prior to performing dives in water of 1.2 m” (p. 38), and coaches should be certain their swimmers are aware of water depth in the competition venue. Thus, Blitvich et al. came to a different conclusion concerning the minimum water depth for racing starts than Welch and Owens (1986) and Gehlsen and Wingfield (1998) by suggesting that 1.2 m is a sufficient minimum water depth provided appropriate instructional and educational practices are in place. The major difference between the studies is that the former study considered the effect of water depth on racing start parameters while the latter studies did not.

Because of this relationship between racing start parameters and water depth *and* because the starts in this study were filmed in deep water, Table 1 may overestimate the risk of swimmers contacting the pool bottom during the execution of racing starts in a 1.22 m water depth. We can adjust the individual means and standard deviations obtained in this study to account for the effect of water depth by using values from a previous study on racing start safety. Cornett et al. (2011d) reported, among other things, the means and standard deviations for maximum head depth for competitive swimmers executing starts in water depths of 1.53 m and 3.66 m. In their study, mean racing start depth was 0.17 m shallower in a 1.53 m water depth than in a 3.66 m water depth and the standard deviation for maximum head depth was 38% lower in 1.53 m water depth as compared to a 3.66 m water depth. We used these values to “correct” our ADJUSTED_MEAN_DEPTH and SD_DEPTH and then recalculated the z scores and the expected percentage of starts deeper than 1.22 m. After the water depth correction, swimmers, as expected, performed fewer racing starts deeper than 1.22 m. The majority of swimmers (19 out of 22, or 86%) seemed to have minimal risk as they were expected to perform fewer than 1 in 10,000 starts deeper than 1.22 m. Two of the swimmers, however, were expected to perform more than 1 in 3 starts deeper than 1.22 m and one of these two still had a mean head depth in excess of 1.22 m.

When we adjusted the mean and variability values in this study to account for the effect of water depth, swimmers were expected to perform fewer racing start deeper than 1.22 m, but two of the swimmers still seemed to be at risk. The problem is that the average water depth correction applied to all swimmers in this study may have under-corrected for some swimmers and these two swimmers specifically. The two swimmers who executed the deepest racing starts in deep water are also the ones who will need to make the largest depth adjustments when moving to a shallower water depth. The important point is that swimmers must recognize pool water depth differences and modify start depth appropriately if they are to perform racing starts in 1.22 m safely. If a swimmer lacks the ability to *consistently control and modify* racing start depth, that swimmer could be at a great risk of injury when performing racing starts in shallow water.

Conclusions and Recommendations

This is the first study to quantify intra-individual racing start depth variability by having the same swimmer execute multiple racing starts in the same experimental conditions. From this analysis, we conclude that it is not sufficient to assess *only*

the maximum head depth from a single racing start, or even the mean value from multiple starts; racing start depth variability must be considered as well. The risk that the swimmer will contact the pool bottom increases as racing start depth variability increases; however, consistent racing start depth alone does not mean that a swimmer is safe executing starts in shallow water. If the swimmer consistently performs deep racing starts, he or she is in danger of contacting the pool bottom. It is also critical that swimmers can accurately perceive water depth—or take steps to become aware of it—and make the appropriate modifications to racing start depth.

As a result, we recommend that swimmers demonstrate racing start depth *consistency* and *control* before being permitted to execute competitive racing starts in shallow water. For example, USA Swimming currently requires that swimmers 11 years of age and older with at least one year of previous competitive experience demonstrate that they are capable of safely controlling racing start depth. We recommend additional requirements before swimmers are permitted to start in shallow water. First, swimmers should be observed to execute racing starts with depth *consistency* by performing multiple racing starts in deep water with minimal racing start depth variability. Once this has been accomplished, the swimmers should demonstrate depth *control* by displaying the ability to consistently execute shallow racing starts.

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