International Journal of Aquatic Research and Education

Volume 5 | Number 2 Article 5

5-1-2011

Block Height Influences the Head Depth of Competitive Racing Starts

Andrew C. Cornett
Indiana University, acornet2@emich.edu

Josh C. White
University of Michigan

Brian V. Wright
Indiana University

Alexander P. Willmott
University of Lincoln

Joel M. Stager
Indiana University

Recommended Citation

Cornett, Andrew C.; White, Josh C.; Wright, Brian V.; Willmott, Alexander P.; and Stager, Joel M. (2011) "Block Height Influences the Head Depth of Competitive Racing Starts," *International Journal of Aquatic Research and Education*: Vol. 5: No. 2, Article 5.
DOI: https://doi.org/10.25035/ijare.05.02.05
Available at: https://scholarworks.bgsu.edu/ijare/vol5/iss2/5

International Journal of Aquatic Research and Education, 2011, 5, 174-186

Block Height Influences the Head Depth of Competitive Racing Starts

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

The purpose of this study was to determine whether or not starting block height has an effect on the head depth and head speed of competitive racing starts. Eleven experienced, collegiate swimmers executed competitive racing starts from three different starting heights: 0.21 m (pool deck), 0.46 m (intermediate block), and 0.76 m (standard block). One-way repeated measures ANOVA indicated that starting height had a significant effect on the maximum depth of the center of the head, head speed at maximum head depth, and distance from starting wall at maximum head depth. Racing starts from the standard block and pool deck were significantly deeper, faster, and farther at maximum head depth than starts from the intermediate block. There were no differences between depth, speed, or distance between the standard block and pool deck. We conclude that there is not a positive linear relationship between starting depth and starting height, which means that starts do not necessarily get deeper as the starting height increases.

There is a prevailing belief that competitive swim start depth increases with starting block height despite limited valid data to support such a notion. In fact, this belief is so prevalent that it has been incorporated into the rules of the sport. The National Federation of State High School Associations (NFHS), the governing body of high school athletics in the United States, does not allow swimmers to execute competitive racing starts from a starting block when the water depth is less than 1.22 m (4 ft), but they do allow swimmers to complete a racing start from the pool deck when the water depth is between 1.07 and 1.22 m (3.5 and 4.0 ft). In enforcing this rule, it would appear that the NFHS is operating under the assumption that competitive racing starts from the pool deck result in shallower starts than those from a standard starting block. To our knowledge, this hypothesis has not been adequately tested.

Competitive racing start depth is an important issue given the potential for serious injury if the swimmer impacts the pool bottom. Mueller and Cantu (2007) reported that all but one of the thirteen catastrophic injuries resulting in "permanent

Andrew Cornett, Brian Wright, and Joel Stager are with the Counsilman Center for the Science of Swimming at Indiana University in Bloomington, IN. Josh White is the men's swimming assistant coach at the University of Michigan in Ann Arbor. Alexander Willmott is with the University of Lincoln, Department of Sport, Coaching, & Exercise Science, Brayford Pool, UK.

severe functional brain or spinal cord disability" within high school and collegiate competitive swimming between 1982 and 2007 occurred during the execution of a racing start. The number of catastrophic injuries over this time period in age group swimming is not readily available and is difficult to estimate as not all competitive programs and swimmers are registered with USA Swimming or any other recognized organizing body.

It is possible to suppose that one catastrophic accident as a result of a racing start is one too many if it was preventable. Consequently, because of the depths swimmers attain during the execution of a racing start, there has been discussion of possible rule changes in order to ensure the safety of swimmers while completing starts. Much of the discussion has focused on changes to the minimum water depth required for competition when using starting blocks. For instance, Gehlsen and Wingfield (1998) reported that none of the swimmers they filmed while performing starts in a 4.0 m deep pool "went deeper than 1.4 m (4.6 ft)." They concluded that minimum water depth should be at least that (4.6 ft) deep. Welch and Owens (1986) recommended that when collegiate swimmers use a 0.76 m (30 in) starting block, minimum water depth be increased to 1.37 m (4.5 ft) as a means of providing "an increased margin of safety in terms of both depth of dive and time to react." Finally, because of the maximum head depths attained during the learning stages of dives, Blanksby, Wearne, and Elliot (1996) recommended that (a) water depths deeper than 1.5 m be used for children learning to execute "block dives," (b) "further scrutiny" occur for the regulation that allows racing starts to be performed in water depth of 1.2 m, and (c) "precise conditions of use" be specified for water depths of 1 m.

While increases in water depth could dramatically lessen the risks associated with executing competitive racing starts, this is impractical in many existing facilities due to time, space, and/or cost constraints. Water depth is only one aspect that aquatic facilities could adapt. Another possibility is to adjust starting block height to a level demonstrated to produce shallower starts. In one study on this topic, Welch and Owens (1986) found collegiate swimmers performed shallower starts from 0.38 m (15 in) starting blocks than from 0.76 m (30 in) starting blocks. They recommended that blocks be changed from 0.76 m to 0.38 m when water depth is less than 1.37 m (4.5 ft). In another study, Blitvich, McElroy, Blanksby, and Douglas (1999) filmed 95 first-year university students executing dives from a standard (0.76 m) block and the pool deck. Although they did not compare the head depths from the two dive conditions, we conducted an analysis on their data using independent sample t-tests and found that block dives were significantly deeper than deck dives ($p < 0.05$). Blanksby et al. (1996) previously reported the dive depths for 26 children (6-8 yrs) in a learn-to-swim program for three different dive types (i.e., a "one foot forward" dive from pool deck, a standing dive from pool deck, and a standing dive from a standard 0.76 m starting block). Again, they did not compare the head depths for the dive conditions, but our analysis of their results using independent samples t-tests indicated that there were no differences in head depth between the dives from the pool deck and the standard starting block. Given the conflicting results, more research is needed to fully understand the relationship between block height and racing start depth.

The purpose of this study is to investigate the effect of starting block height on competitive racing starts executed by experienced swimmers. Three block heights were used in this study (i.e., the pool deck, an intermediate height block, and a standard height block) so that we could determine whether or not maximum head depth changes as a function of starting height. This information could aid in evaluation of risks and development of safety regulations pertaining to block height and water depth in competitive swimming.

Method

Participants

Eleven collegiate swimmers (5 females and 6 males) participated in this study with a mean age of 20.1 ± 1.2 years, standing height of 1.79 ± 0.08 m, and mass of 74.5 ± 8.9 kg. The participants were all members of collegiate swim teams and USA Swimming registered. No other criteria were used in the selection process other than these memberships. 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 after written and verbal explanations of the study were provided.

Experimental Procedure

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 that included two starting platforms (intermediate block and standard block) was custom-designed for the project (Adolph Kiefer and Associates, Zion, IL). For starts from the pool deck, a mat was placed beside the starting blocks to prevent the subjects from slipping when performing the competitive starts. The block was mounted on a steel frame 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 three competitive starts in random order, one from each of three starting heights above the water level: 0.21 m (pool deck), 0.46 m (intermediate block), and 0.76 m (standard block). Each trial mimicked a competitive situation where 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). No instructions were given to the swimmers other than to execute their "typical" racing start. Following the start, swimmers performed a front crawl (freestyle) sprint midway across the pool. The participants were not aware of the purpose of the study so as to not affect their starting behavior. Based on the goal of a sprint swim, the participants most likely believed that speed and/or time to mid-pool was the central purpose of the study.

Video Recording

A Canon GL2 digital video camcorder (Canon Inc., Tokyo, Japan) was utilized for video recording. The camera was enclosed in a sealed housing unit (Ikelite Underwater Systems, Indianapolis, IN), mounted on a heavy tripod (Hercules model, Quick-Set Inc., Northbrook, IL) and placed on the bottom of the pool. The camera was aligned perpendicular to the direction of the racing start, and a Canon WD-58 wide-angle adapter (Canon Inc., Tokyo, Japan) was used to ensure that the field of view included the participants' underwater motions from entry until farther than the deepest point of the racing start. 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 starting 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, approximately 0.05 m in diameter, were located at regular intervals around the frame.

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 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 towards 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

Fisher's Least Significant Difference (LSD) test was used to analyze the data. Briefly, this procedure consisted of two steps. First, the equality of means was tested using a univariate analysis of variance (ANOVA) F test. If the null hypothesis for the omnibus F test was rejected, pairwise comparisons were conducted using α-level t tests. If the null hypothesis for any t test was rejected, the corresponding means were declared unequal (Hayter, 1986). A major criticism of the LSD procedure is

DOI: https://doi.org/10.25035/ijare.05.02.05

that maximum familywise error is known to increase above the nominal level as the number of groups gets large. Hayter found that the maximum familywise error rate is maintained at the nominal level α when the number of groups is equal to three or less. Since we had three groups in this study, we utilized this procedure without substantially inflating familywise error.

For the F tests, the sphericity assumption was tested using Mauchly's Test of Sphericity. If the sphericity assumption was violated, the Greenhouse-Geisser sphericity correction was used to alter the degrees of freedom and thus raise the significance of the F-ratio. For all analyses reported below, an alpha level of 0.05 was used to determine statistical significance.

Results

The values for the head variables for the three block heights are presented in Table 1. The one-way repeated measures ANOVA yielded a significant main effect for block height for maximum depth of the center of the head, $F(2, 20) = 11.61$, $p < 0.001$, partial $\eta^2 = 0.54$; head speed at maximum head depth, $F(2, 20) = 8.20$, $p = 0.003$, partial $\eta^2 = 0.45$; and distance from the wall at maximum head depth, $F(2, 20) = 14.95$, $p < 0.001$, partial $\eta^2 = 0.60$.

The pairwise comparisons indicated that the maximum depth of the center of the head was significantly deeper for racing starts from the standard block than the intermediate block ($p = 0.001$) and from the pool deck than intermediate block ($p = 0.003$; Figure 1). Similarly, head speed at maximum head depth was significantly faster for starts from the standard block than the intermediate block ($p = 0.001$) and from the pool deck than the intermediate block ($p = 0.024$; Figure 2). Finally, distance from the starting wall at maximum head depth was significantly greater for starts from the standard block than the intermediate block ($p < 0.001$) and from the pool deck than the intermediate block ($p = 0.004$; Figure 3).

Table 1 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)

Block Height (m)	N	Maximum Depth of the Center of the Head (m)			Head Speed at Maximum Head Depth (ms-1)	Distance from the Wall at Maximum Head Depth (m)
		Minimum	Mean	Maximum		
0.21	11	0.73	0.93 ± 0.16	1.25	2.88 ± 0.52	5.46 ± 0.81
0.46	11	0.56	0.83 ± 0.18	1.19	2.43 ± 0.42	4.71 ± 0.85
0.76	11	0.73	1.00 ± 0.21	1.32	2.97 ± 0.45	5.55 ± 0.49

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

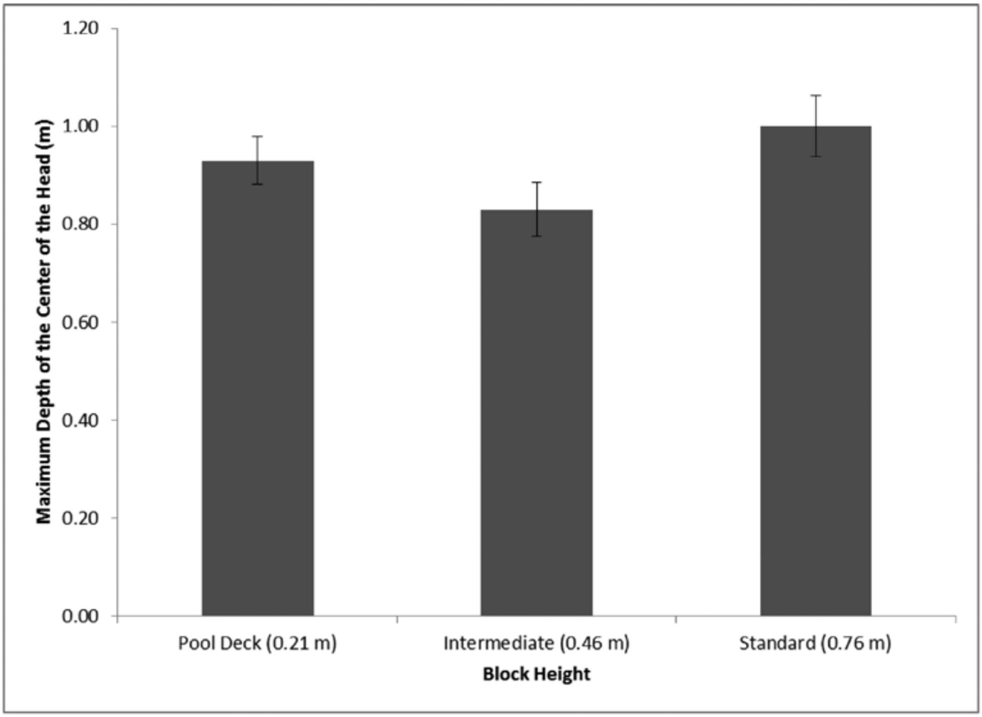

Figure 1 — Maximum depth of the center of the head as a function of block height (pool deck, 0.21 m; intermediate block, 0.46 m; standard block, 0.76 m). Starts from the standard block and pool deck were significantly deeper ($p < 0.05$) than starts from the intermediate block. Error bars represent one standard error.

Discussion

The purpose of this study was to investigate the relationship between the maximum depth of the center of the head depth during the completion of a competitive racing start and starting platform height. Specifically, we wanted to test the prevailing assumption in swimming that the depth of a competitive racing start decreases with a lower starting height. In this regard, the primary finding of the study was that the head depths of racing starts were significantly greater from a standard starting block (0.76 m) and the pool deck (0.21 m) as compared to an intermediate height (0.46 m) starting block, and perhaps as important, resultant head depths from the highest and lowest vertical starting heights were not different from each other. This suggested that racing start depth does not necessarily decrease in a linear fashion with a decrease in starting height.

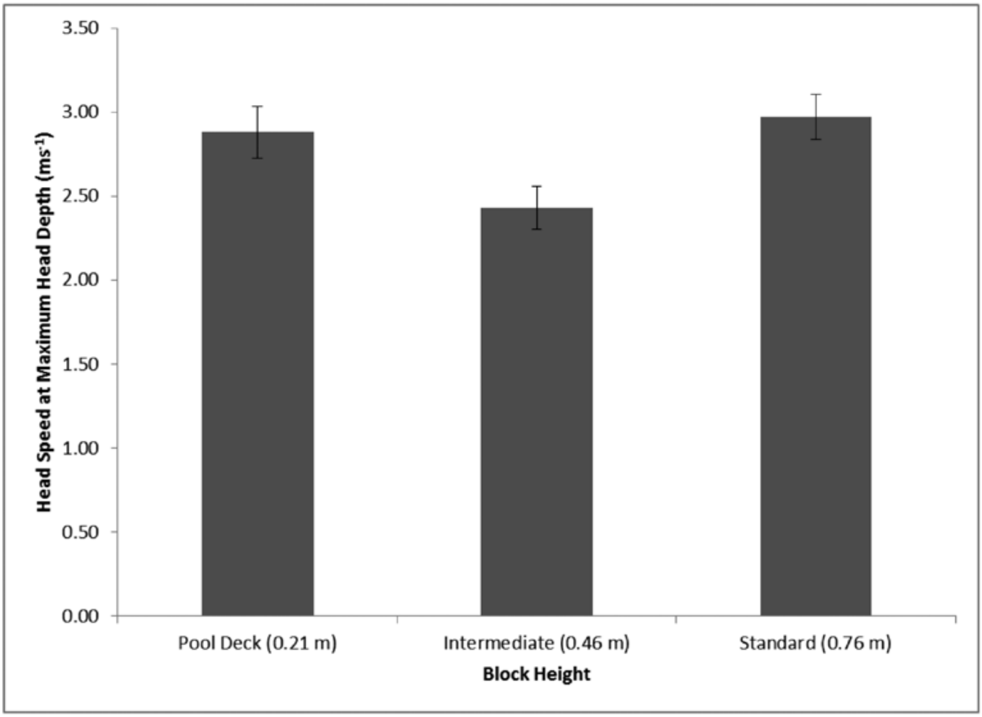

Figure 2 — Head speed at maximum head depth as a function of block height (pool deck, 0.21 m; intermediate block, 0.46 m; standard block, 0.76 m). Starts from the standard block and pool deck were significantly faster ($p < 0.05$) than starts from the intermediate block. Error bars represent one standard error.

Maximum Depth of the Center of the Head

The finding of deeper starts from a standard 0.76 m block as compared to a lower intermediate (0.46 m) block is not without precedent. Welch and Owens (1986) had filmed 30 collegiate swimmers while they executed both a pike start and a flat start from 0.38 m (15 in) and 0.76 m (30 in) starting blocks. They reported significant main effects for start type and block height with deeper starts being executed for pike starts than conventional starts (0.72 m vs. 0.57 m, respectively) and for starts from a 0.76 m block than a 0.38 m starting height (0.68 m vs. 0.61 m, respectively). They concluded that the degree of risk of catastrophic injury from striking the pool bottom increased progressively for a conventional start from a 0.38 m starting height to a conventional start from a 0.76 m starting height. Welch and Owens (1986) recommended that starting platform height "should be lowered to below 15 in or eliminated entirely" in the absence of appropriate water depths (which according to Welch and Owens were 1.37 m or 4.5 ft). The first portion of the Welch and Owens recommendation appeared consistent with their findings; however, because they did not evaluate starts executed from the pool deck,

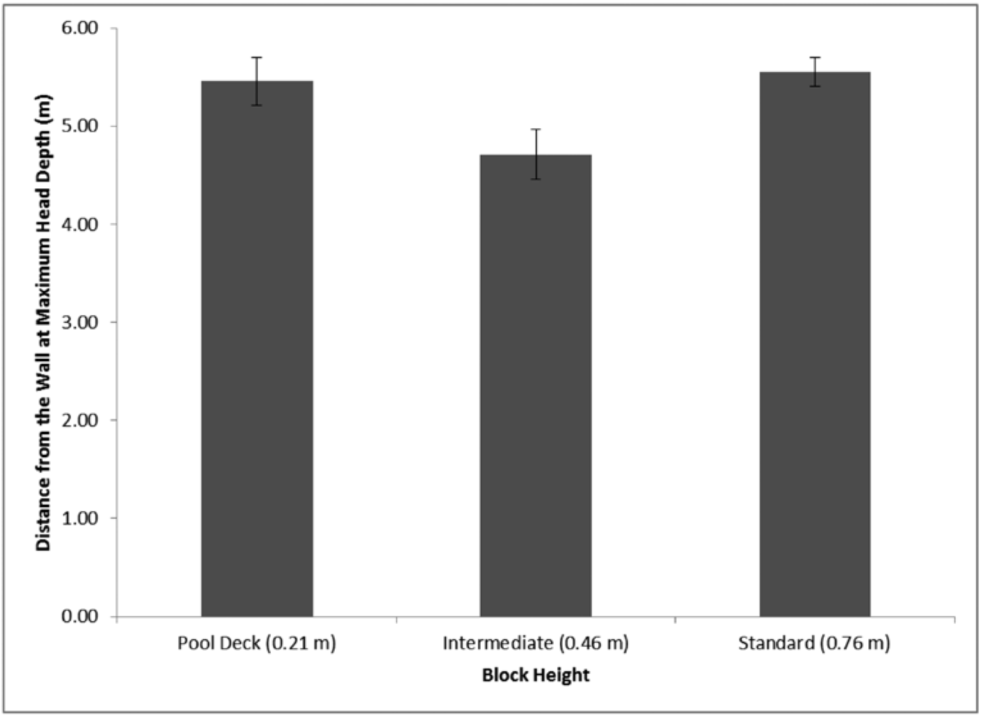

Figure 3 — Distance from the starting wall at maximum head depth as a function of block height (pool deck, 0.21 m; intermediate block, 0.46 m; standard block, 0.76 m). Starts from the standard block and pool deck were significantly greater ($p < 0.05$) than starts from the intermediate block. Error bars represent one standard error.

the latter part of their recommendation (i.e., "eliminated entirely") is beyond the scope of their analysis. Their results were similar to the current analysis in which collegiate swimmers executed significantly deeper starts from a standard (0.76 m) starting height than from an intermediate (0.46 m) starting height. What differs is that Welch and Owens did not measure head depth from the pool deck whereas we found head depth to be significantly deeper from the pool deck than from the intermediate height.

Gehlsen and Wingfield (1998) also had conducted an investigation that examined the effect of start type (pike vs. flat) and starting platform height (0.46 m, 0.56 m, 0.66 m, and 0.76 m) on racing start parameters. Twenty collegiate swimmers executed five starts for each start type and starting height. They reported significant main effects for start type and starting height. The pike starts were significantly deeper than the flat starts (approximately 0.95 m vs. 0.85 m, respectively). In addition, Gehlsen and Wingfield (1998) interpreted the significant main effect for starting height to mean that "as the height of each dive increased, the vertical displacement of the head increased." Unfortunately, they did not provide results of pairwise comparisons between their four starting heights. Judging from the graphical display of their data, their interpretation and stated conclusions seem questionable. The "mean underwater head vertical displacement values at the lowest point in the dive" appear equivalent for the lowest (0.46 m) and highest (0.76 m) starting heights. Only head depths from the 0.56 m starting height appear to be lower than those from the other block heights. Further specific conclusions cannot be drawn without running additional pairwise comparisons. Reanalysis of their data is not possible as a result of missing numeric values and data variances.

To our knowledge, there are no other studies reporting the maximum head depth of experienced swimmers during a competitive racing start from a standard height (0.76 m) starting block as compared to starts from a pool deck. There are, however, two studies (Blitvich et al., 1999; Blanksby et al., 1996) that have compared the head depth from standing dives from a starting block and the pool deck. In the first such study, Blitvich et al. (1999) filmed 95 first-year university students executing four different types of dives: a deck dive, a block dive, a running dive, and a treadwater dive. The aim of their study was to "determine which factors make the most contribution to the level of risk in diving" and not necessarily to compare the maximum head depth for the different dive conditions. We were able to infer using independent sample t-tests differences between the deck dive (0.49 ± 0.19 m) and block dive (0.64 ± 0.27 m) using the means, standard deviations, and sample sizes provided in their article. Our analysis showed that the maximum depth of the head for block dives was significantly deeper than deck dives ($p < 0.05$). This finding is inconsistent with the results obtained in our current investigation, where we did not detect differences in head depth between racing starts from the pool deck and a standard starting height. When comparing our results with this study, it is important to recognize that the participants in the study by Blitvich et al. (1999) were instructed "to perform a shallow dive." We did not give swimmers in our study verbal instruction other than to perform their typical racing start. Two additional critical differences between the studies are (a) the use of swimmers of different skill and experience levels (i.e., inexperienced first year university students vs. experienced collegiate swimmers) and (b) the execution of different tasks in the studies (i.e., standing shallow dive vs. competitive racing start).

Blanksby et al. (1996) also had reported dive depths from the pool deck and a standard starting block. They studied 26 children (6–8 yrs) in a "Uniswim" (i.e., learn-to-swim) program and remarked that while the children were able to perform a standing dive from a standard 0.76 m starting block, they were "not highly skilled." They filmed various types of dives from different developmental levels of diving. Three types of dives were relevant to the discussion on head depth and starting height: the "one foot forward standing dive," the "standing dive on edge," and the "block dive." The authors' focus was upon examining the safety factors associated with incremental stages of diving and not necessarily on comparing the maximum head depths between the dive conditions. When we made these comparisons using their data, we found that there was not a significant difference in head depth between either of the deck dives and the block dive (independent samples t-test; $p > 0.05$). It is important to note that we conducted an independent samples t-test even though all children completed each of the dive conditions. Since we did not have the data for individual participants, we were not able to compute a dependent samples t-test which has greater statistical power. Nevertheless, the nonsignificant result is consistent with the results from our present analysis, where there was no difference in maximum depth of the center of the head when college-age competitive swimmers executed starts from a standard 0.76 m starting height and the 0.21 m pool deck. Once again, it needs to be emphasized that there were important differences between the current study and the research by Blanskby et al. (1996). The participants in our analysis were significantly older (20.1 ± 1.2 yr vs. 6.9 ± 0.9 yr) and more experienced (collegiate swimmers vs. beginners) and the tasks were different between the studies (racing starts vs. dives). To our knowledge, there is no other quantitative based literature with which to compare our data.

The finding of deeper starts from the pool deck than from an intermediate starting height (0.46 m) is novel and somewhat nonintuitive. We have not been able to find any studies where the maximum depth of the center of the head was compared for competitive racing starts from the pool deck and an intermediate height starting platform height (e.g., 0.46 m). This suggests that when water depth is a concern an intermediate starting height, such as 0.46 m, could be safer to use than either a standard 0.76 m starting height or the pool deck of 0.21 m. Before such a recommendation is invoked as a rule, we strongly recommend that further analysis on maximum head depth be conducted in order to ensure that swimmers younger and/or less experienced than those used in the present study also demonstrate shallower starts from an intermediate starting height than the pool deck.

Head Speed at Maximum Head Depth

Up to this point, our discussion has focused on the maximum depth of the center of the head attained during the execution of a competitive racing start from different starting heights. In terms of start safety, head speed at maximum head depth is very relevant because it represents the combination of head depth and head speed that is important in assessing the safety consequences of racing starts. Statistical analysis revealed that head speed for racing starts from the standard (0.76 m) starting height and the pool deck both were significantly greater than for starts from an intermediate starting height (0.46 m) despite being deeper than those from the intermediate block height. This finding was unexpected as previous research had demonstrated that shallower racing starts are either consistent with greater head speed at maximum head depth (Cornett, White, Wright, Willmott, & Stager, 2011a; Cornett, White, Wright, Willmott, & Stager, 2011b; White, Cornett, Wright, Willmott, & Stager, 2011) or no difference in head speed at maximum head depth (Blitvich, McElroy, Blanksby, Clothier, & Pearson, 2000; Cornett, White, Wright, Willmott, & Stager, 2011c).

Previously, we suggested that shallower racing starts are consistent with greater head speed at maximum head depth because swimmers travel through less water both vertically and horizontally during a shallower start and therefore lose less momentum due to lower drag forces of the water on the body (Cornett et al., 2011a). As a result, explaining why racing starts from the standard starting height and pool deck were faster at maximum head depth than starts from the intermediate starting height is difficult. We speculate that this may be related to practice, specifically with respect to the intermediate platform starts. The collegiate swimmers we studied had likely executed hundreds, if not thousands, of racing starts from standard starting platform heights in their careers. Further, these swimmers likely had performed a countless number of dives from the pool deck when entering the water. With so many repetitions from the standard starting height and pool deck, the swimmers had likely determined through trial and error how to execute the task in such a way as to maximize head speed at maximum head depth. They had not had many opportunities to practice competitive racing starts from intermediate starting heights because these blocks are uncommon, if not nonexistent, in competitive aquatic venues. It is possible that the swimmers had not determined the best movement solution, again through trial and error, from the intermediate starting height. The opportunity to do so had not readily existed for them. This in turn could have resulted in less than ideal take-off and entry angles, which could then result in a less than optimal trajectory. If this was indeed the case, we would expect a less "clean" entry to result in slower head speeds at maximum head depth. Again, this is speculation on our part because we did not attempt to quantify the quality of the entry or the number of starts performed from various starting heights throughout their careers nor did we conduct an intervention to provide practice in starting from an intermediate level starting block.

Regardless of the reason, the finding of slower head speeds at maximum head depth, in combination with the finding of shallower head depths, from an intermediate starting height may have important implications for racing start safety. If starts are indeed slower and shallower from a 0.46 m starting height, partially lowering the starting block height (but not to deck level height) could possibly serve to lessen the risk associated with competitive racing starts when water depth is a concern. More research is necessary in order to determine whether or not starts at this intermediate height get deeper and faster with practice.

Distance from the Wall at Maximum Head Depth

The finding of greater distance from the wall at maximum head depth from the standard starting height and the pool deck than from the intermediate starting height was in line with previous research. Several studies had demonstrated that as head depth increased, so too did distance from the wall at maximum head depth (Blitvich et al., 2000; Cornett et al., 2011a, 2011b, 2011c; White et al., 2011). White et al. (2011) suggested that shorter distance from the wall was 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."

Conclusion

The current operating assumption in competitive swimming is that lowering the height of the starting surface is linearly associated with reducing the risks of executing a racing start as a result of slower speeds, less distance, and less depth during the start. This hypothesis has never been sufficiently tested although Blanksby et al. (1996), who observed children completing dives commonly incorporated into incremental progressions for learning to dive, reported that a greater percentage of dives exceeded a "threshold depth" of 1.52 m from the standing deck dives when compared to "block" dives. Depths greater than 1.52 m with vertical head speeds greater 0.6 ms^{-1}, a proposed threshold for speeds fast enough "to dislocate the adult cervical spine" at 1.52 m (Stone, 1981) occurred more frequently in "one foot forward" dives than the block dives. The number of observations was small in their study; nevertheless, combined with our results, these findings are particularly important given that current National Federation of State High School Associations (NFHS, 2009) rules permit swimmers to execute starts from the pool deck when the water depth is between 1.07 and 1.22 m. Our results showed that competitive racing starts may be deeper and faster at maximum head depth from a standard starting platform height (0.76 m) and the pool deck (0.21 m) than from an intermediate starting platform height (0.46 m), but are not different from each other. Therefore, from the perspective of speed and/or head depth, we conclude that the assumption that deck starts are safer in shallow water than standard block starts may be incorrect. Regulations pertaining to racing starts should reflect these findings.

Acknowledgments

Financial support for the project was received from a grant from United States Sports Insurance Company (USSIC) to USA Swimming. Adolph Keifer and Associates are thanked for providing the custom starting platforms essential for this research. We would like to thank John Petersen of Risk Management Services, Inc. and Ron Van Pool, Murray Stevens, and Carol Zaleski of USA Swimming, who were fundamental in providing support and important input. Dr. Paul B. Sigfusson, DDS, deserves special recognition as liaison with USSIC and USA Swimming and important project advisor.

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*, 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*, 553-559.

Blitvich J.D., McElroy, G.K., Blanksby, B.A., Clothier, P.J., & 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. (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. (2011b). Water depth influences the head depth of competitive racing starts. *International Journal of Aquatic Research and Education, 5*, 32-41.

Cornett, A.C., White, J.C., Wright, B.V., Willmott, A.P., & Stager, J.M. (2011c). Ability of adolescent competitive swimmers to modify start depth is not dependent upon age. *International Journal of Aquatic Research and Education, in review*.

Gehlsen, G.M., & Wingfield, J. (1998). Biomechanical analysis of competitive swimming starts and spinal cord injuries. *Journal of Swimming Research, 13*, 23-30.

Hayter, A.J. (1986). The maximum familywise error rate of fisher's least significant difference test. *Journal of the American Statistical Association, 81,* 1000-1004.

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.

National Federation of State High School Associations. (2009). *2009-10 NFHS swimming and diving and water polo rules book.* Indianapolis, IN: Author.

Stone R.S. (1981). Canadian Medical Association Journal 1981, 124(May), 1323-1324 as cited in 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*, 79-85.

USA Swimming. (2010). *2010 USA swimming rules and regulations*. Colorado Springs, CO: Author.

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

White, J.C., Cornett, A.C., Wright, B.V., Willmott, A.P., & Stager, J.M. (2011). Ability of competitive swimmers to modify racing start depth. *International Journal of Aquatic Research and Education, in press*.