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Andrew C. Cornett
Eastern Michigan University, acornet2@emich.edu

Josh C. White
University of Michigan

Brian V. Wright
Austin College

Alexander P. Wilmott
University of Lincoln

Joel M. Stager
Indiana University

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Racing Start Safety: Head Depth and Head Speed During Competitive Backstroke Starts

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

Research on competitive swim start safety has focused on starts involving a dive from above the water surface. The purpose of this study was to determine the depths, speeds, and distances attained when executing backstroke starts, which begin in the water, and to investigate whether or not these variables are a function of age. Backstroke starts (n = 122) performed in 1.22 m of water during competition were stratified according to age group (8&U, 9-10, 11-12, 13-14, and 15&O). Dependent measures were maximum depth of the center of the head (MHD), head speed at maximum head depth (SPD), and distance from the wall at maximum head depth (DIST). Main effects were shown for age group for MHD ($F = 8.86$, $p < 0.05$), SPD ($F = 4.64$, $p < 0.05$), and DIST ($F = 17.21$, $p < 0.05$). Because they performed starts that were deeper and faster than the younger swimmers, the older swimmers seem to be at a greater risk for injury when performing backstroke starts in shallow water.

The racing start may be the aspect of competitive swimming that is the most inherently risky. In support of this, a study spanning a 25-year period (1982–2007) reported 13 catastrophic injuries resulting in "permanent severe functional brain or spinal cord disability" within competitive swimming (high school and college) with all but one incident occurring during the execution of a racing start from a block (Mueller & Cantu, 2007). As a result, examination of the various parameters pertaining to the racing start, as a means of identifying the level of risk these factors represent, seems appropriate. Variables that are relevant in this regard primarily relate to the depth and speed swimmers attain during the execution of racing starts. These two variables dictate to a large extent the inertial forces generated during a start.

Of the four strokes contested in competitive swimming events, three (freestyle, butterfly, and breaststroke) utilize a starting block and involve a forward dive from above the water surface and one (backstroke) is executed from within the water. To date, research on racing starts has focused exclusively on forward block starts and

Andrew Cornett is with Eastern Michigan University, School of Health Promotion and Human Performance, Ypsilanti, MI. Josh White is the men's swimming assistant coach at the University of Michigan, Ann Arbor, MI. Brian Wright is the men's and women's head swimming coach at Austin College, Sherman, TX. Alexander Willmott is with the University of Lincoln, Department of Sport, Coaching, & Exercise Science, Brayford Pool, UK. Joel Stager is the director of the Counsilman Center for the Science of Swimming at Indiana University, Bloomington, IN.

no consideration has been given to the safety of swimmers executing backstroke starts. The reason for a lack of research on the backstroke start is not entirely clear. It may be because there have been no documented catastrophic injuries in competitive swimming involving backstroke starts (Mueller & Cantu, 2007), and thus the assumption is that the head depths and speeds of backstroke starts are substantially less than block starts. Recent trends in the execution of the backstroke start, with particular reference to the development and use of the underwater dolphin kick, warrants examination of this assumption.

National governing bodies in the sport (e.g., USA Swimming and National Federation of State High School Associations) enforce rules regarding minimum water depths for the execution of racing starts from a starting block as a means of safeguarding athletes. For instance, as a mandatory requirement in all sanctioned competitions, USA Swimming requires that "in pools with water depth less than 4 feet (1.22 meters) at the starting end, the swimmer must start from within the water" (USA Swimming, 2011, p. 44). This stipulation prevents swimmers from starting from a block into water less than 4 ft deep. The National Federation of State High School Associations (NFHS) enforces a similar rule (NFHS, 2010). Because backstroke starts are initiated from within the water, the current rules apparently do not pertain to the execution of these starts. This can be interpreted as there is currently no minimum water depth required for the execution of backstroke starts while in competition.

The research on forward block starts has consistently shown that during competition, older swimmers are at greater risk than younger swimmers when performing starts in shallow water because they attain deeper head depths and sustain faster head speeds (Cornett, White, Wright, Willmott, & Stager, 2010, 2011). These findings are unlikely to be due to "age," per se; rather, body size, strength, experience, and technical skill are likely to contribute. It seems probable that a similar relationship would exist between age and backstroke start depth and speed. If so, older swimmers would be at a greater relative risk than younger swimmers when executing backstroke starts in shallow water. This hypothesis remains to be tested.

Thus, the primary purpose of this study is to add to the body of knowledge of racing start safety by describing important parameters of the backstroke start during competition, the only racing start not currently limited by water depth rules. A secondary purpose is to determine whether or not the backstroke start parameters vary as a function of the ages of the swimmers.

Methods

The study took place during a USA Swimming sanctioned age group and open invitational swim meet at a competitive pool in central Indiana. The facility consisted of an eight lane competition pool with a starting end depth of 1.22 m. Starting platforms were standard 0.76 m blocks with handles for the execution of backstroke starts (55.5 cm above water surface and 46.3 cm wide). The project was previously approved by the university's Human Subjects Committee.

Participants

The subjects participating in this study were USA Swimming registered competitive swimmers ranging in age from 6-16 years. There were no minimal time standards

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for participation in the competition and therefore swimmers represented a wide range of skill levels. Only starts performed in lanes four and five were filmed as a result of the required camera position. Thus, one limitation of the study that should be acknowledged is that the swimmers filmed were those with the two fastest entry times of the eight swimmers in each heat. These swimmers are likely to be the most skilled performers, meaning that for each heat, the starts of the least skilled swimmers are not being recorded. As the meet had multiple backstroke events, it was possible for a single subject to be represented in the data multiple times. Identification of the subjects was prohibited by the human subjects committee and therefore the exact number of individuals filmed in each age group is not specifically known. Regardless, "starts" rather than specific swimmers in each age group is considered the more critical of the two descriptors.

Procedures

All filming took place in a competitive pool specifically selected because it had sufficient space outside of the competition area in lanes one and eight for cameras to be positioned. For each heat, the underwater portion of the racing start for the swimmers in lanes four and five was recorded using a two-camera system. Video recording began at the start signal of the race and continued until the swimmers passed completely through the field of view. Canon GL2 (Canon Inc., Tokyo, Japan) digital video camcorders, enclosed in underwater housing units (Ikelite Underwater Systems, Indianapolis, IN), were placed on the pool bottom. The cameras were located approximately 6.5 m from the pool start wall on the outer edge of lanes one and eight and were at an angle of approximately 45° to the pool start wall. Canon wide-angle adapters (WD-58, Canon Inc., Tokyo, Japan) were used to ensure that the field of view included the subjects' underwater motions from water entry to beyond the deepest point of the racing start. Camera zoom and focus were adjusted remotely underwater once the camera unit was in place. Opticis Optical IEEE1394 FireWire Repeaters (M4-100, Opticis North America, Inc., Chatham, Ontario, Canada) extended the range of the video cables to 30 m and enabled both video signals to be input directly to a single laptop computer (M675, Gateway Inc., Irvine, CA) at the poolside. Video sequences were recorded at 60 Hz using motion software (SIMI Reality Motion Systems, Unterschleissheim, Germany), which determined the time offset between the video signals from the two cameras to permit accurate three dimensional (3D) reconstruction.

Calibration

Separate calibrations were undertaken for lanes four and five. For each, a custom-built calibration frame was placed in the region of the racing start and filmed with both cameras. The dimensions of the frame were 1 m × 1 m × 3 m and it was constructed from marine aluminum, which was painted black. Eighty-four bright yellow closed-cell foam marker balls (0.05 m diameter) served as calibration points.

The calibration frame was placed vertically in line with the center of the starting block and perpendicular to the side of the pool. Additionally, a vertical plumb line with three marker balls and three additional balls floating at the surface were included in the field of view and a video image was captured with each camera.

The positions of the 84 marker balls on the frame, the additional marker balls, and reference points on the wall of the pool were digitized in a single video frame from each camera using SIMI Motion. The balls on the frame were used in the 3D direct linear transformation (DLT) procedure to calibrate the area using a frame-based coordinate system. The data on the positions of the additional markers enabled the transformation of position data from the frame-based system to a pool-based reference frame in which the x-axis was horizontal and perpendicular to the wall, the y-axis pointed horizontally to the left, and the z-axis pointed vertically upward. The origin was at water level directly below the center of the starting block for that lane.

Filming and Data Analysis

All backstroke starts during the competition in lanes four and five were recorded and included in this analysis. For each trial, the center of the head was digitized using the external auditory meatus as a landmark. The frame in which the head reached its maximum depth was first visually estimated by the experimenter, and an additional 10 frames were digitized to ensure that the true instant of maximum depth had been included. When a landmark was obscured or its location could not be determined from both camera angles, the start was excluded from the analysis.

The dependent measures of interest for this study were maximum depth of the center of the head, head speed at maximum head depth, and distance from the wall at maximum head depth. The starts were stratified according to age group. Similar to what others have reported (Counsilman, Nomura, Endo, & Counsilman, 1988; Cornett et al., 2010), preliminary comparisons found no differences between boys and girls for the dependent variables. As a result, we limited our comparisons to age group by pooling the sexes. The age groups were for swimmers 8 years and under (8&U), 9 to 10 years (9-10), 11 to 12 years (11-12), 13 to 14 years (13-14), and 15 years and older (15&O).

One-way independent groups ANOVAs were conducted to investigate the effect of age on the maximum depth of the center of the head, head speed at maximum head depth, and distance from the wall at maximum head depth of backstroke starts. When a significant F-ratio was obtained from the omnibus ANOVA test, all pairwise age group comparisons were performed using Tukey's HSD procedure. For all analyses described above, an alpha level of 0.05 was used to determine statistical significance.

Results

Table 1 displays means and ranges for each age group for maximum depth of the center of the head, head speed at maximum head depth, and distance from the wall at maximum head depth. The one-way ANOVAs showed a significant effect for maximum depth of the center of the head, head speed at maximum head depth, and distance from the wall at maximum head depth, $F(4, 117) = 8.86$, $p < 0.001$; $F(4, 117) = 4.64$, $p = 0.002$; and $F(4, 117) = 17.21$, $p < 0.001$, respectively (see Figures 1-3).

Pairwise comparisons showed that 8&U starts were significantly shallower than starts for all other age groups ($p < 0.05$), 9-10 starts were significantly shallower than 13–14 and 15&O starts ($p < 0.05$), and 11–12 starts were significantly shallower than 15&O starts ($p < 0.05$). Also, pairwise comparisons showed that head

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

Age Group	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)	
		Mean	Maximum	Mean	Maximum	Mean	Maximum
8&U	12	0.17 ± 0.13	0.41	1.03 ± 0.49	1.75	2.39 ± 0.55	3.27
9-10	36	0.30 ± 0.14	0.64	1.30 ± 0.31	2.26	2.91 ± 0.48	3.67
11-12	41	0.36 ± 0.19	0.77	1.44 ± 0.31	1.93	3.19 ± 0.55	4.32
13-14	24	0.43 ± 0.21	0.86	1.47 ± 0.29	2.02	3.52 ± 0.61	5.25
15&O	9	0.57 ± 0.16	0.88	1.37 ± 0.30	1.91	4.11 ± 0.57	5.11

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

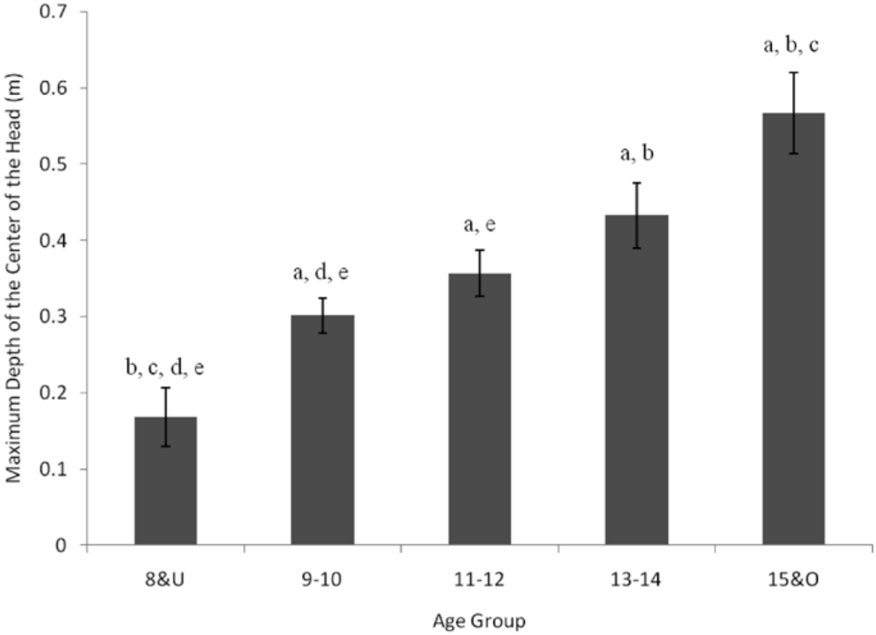

Figure 1 — Maximum depth of the center of the head (m) as a function of age group (yr; a- 8&U, b- 9-10, c-11-12, d- 13-14, and e- 15&O). Significant differences ($p < 0.05$) denoted by letter above each bar. Error bars represent one standard error.

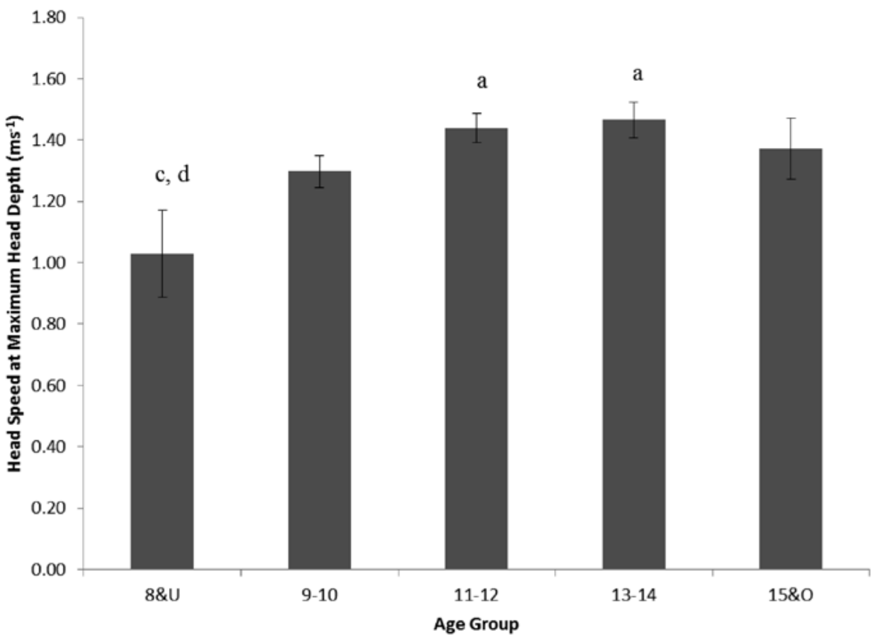

Figure 2 — Head speed at maximum head depth (ms^{-1}) as a function of age group (yr; a- 8&U, b- 9-10, c-11-12, d- 13-14, and e- 15&O). Significant differences ($p < 0.05$) denoted by letter above each bar. Error bars represent one standard error.

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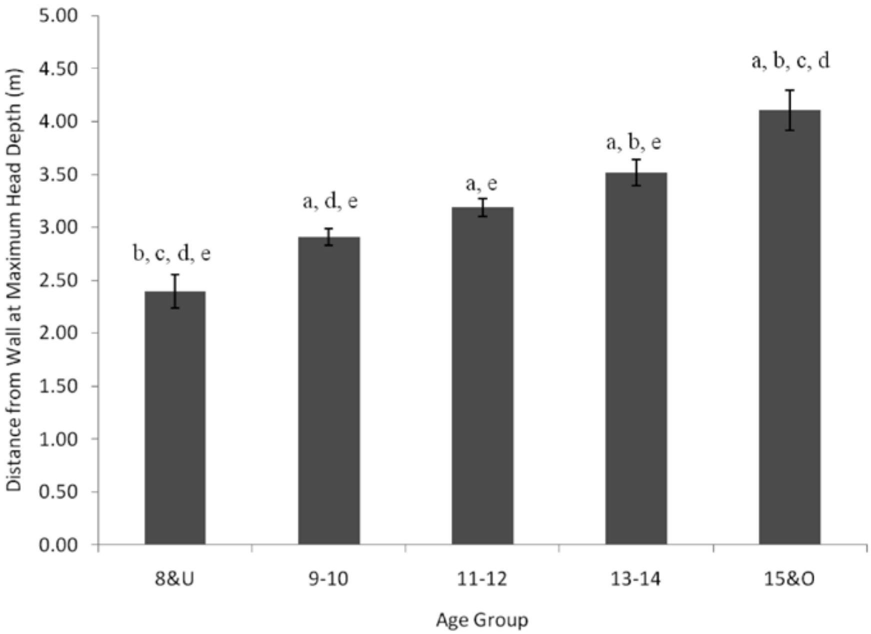

Figure 3 — Distance from the wall at maximum head depth (m) as a function of age group (yr; a- 8&U, b- 9-10, c-11-12, d- 13-14, and e- 15&O). Significant differences ($p < 0.05$) denoted by letter above each bar. Error bars represent one standard error.

speed at maximum head depth was significantly slower for 8&U starts than 11–12 and 13–14 starts ($p < 0.05$). Finally, all pairwise comparisons for distance from the wall at maximum head depth were statistically significant ($p < 0.05$) with the exception of the comparisons between 9-10 and 11–12 starts and between 11–12 and 13–14 starts.

Discussion

The primary purpose of this study was to contribute to the body of knowledge of racing start safety by describing important parameters of the competitive backstroke start. We were unable to locate any previous literature describing the relevant variables (head depth and speed) pertaining to the underwater portion of the backstroke start. This is an important issue because at least two major national governing bodies of swimming in the United States (i.e., USA Swimming and National Federation of State High School Associations) do not enforce a minimum water depth for the execution of backstroke starts (NFHS, 2010; USA Swimming, 2011). Water depth rules pertain only to forward block starts from an elevated starting platform. From the perspective of swimmer safety, the most important findings of the present study relate to the maximum head depths and head speeds observed.

Maximum Depth of the Center of the Head

Table 1 displays the maximum depth of the center of the head relative to the surface of the water for the backstroke starts analyzed. While these values are informative, from the perspective of safety, it might be more instructive to consider the distance between the pool bottom and the external surface of the head. Previously, Blitvich, McElroy, Blanksby, and Douglas (1999) adjusted their measured head depths (using the external auditory meatus as the landmark) by adding 0.15 m as a means to estimate the deepest point of the external surface of the head (external head depth). To derive the distance from the external surface of the head to the bottom of the pool, 0.15 m was likewise added to our values for maximum depth of the center of the head and then this external head depth was subtracted from the pool water depth.

Using these values, the oldest swimmers (15&O) came closest to the bottom with their external head depth being, on average, 0.50 m from the bottom. In addition, the least distance from the pool bottom of all starts filmed occurred within this group at 0.19 m. The starts performed by the youngest group (8&U) were the farthest from the bottom and averaged 0.90 m. The start with the least distance from the bottom executed by a swimmer within this age group resulted in a distance of 0.66 m. Four of the five starts the farthest from the bottom were executed by swimmers within this age group with an average distance of 1.0 m.

Regression of maximum head depth on age revealed a statistically significant linear trend ($F = 38.25$, $p < 0.001$), indicating that the maximum head depth attained increased as a function of the swimmers' age. The oldest swimmer filmed during this competition was a 16-yr-old and as a result, we cannot say whether or not there would continue to be a linear relationship between head depth and age for swimmers beyond this. It seems reasonable to hypothesize that there is an age at which backstroke start head depth stops increasing as a function of age. At which age this occurs is not known. Because filming was completed in the "public domain" without requiring specific individual consent, we were unable to obtain measures of height, weight, or other variables that might further explain the inter-individual variance. The equation derived from regression above (Distance of the Head from the Bottom = 1.195 – 0.043*Age), however, allows us to predict a mean head distance from the pool bottom of 0.29 m for 21-yr-old swimmers (assuming that the relationship between head depth and age is stable beyond 16 yr). Twenty-one years was chosen for this estimate as it represents an age beyond which the majority of swimmers have completed their competitive careers. We recognize the problems associated with predicting depth for swimmers outside of the age range filmed. This prediction, however, demonstrates the need to better characterize backstroke starts for swimmers 17 yrs and older, given there is no enforceable rule that addresses a minimum water depth for backstroke starts in competition.

From the perspective of head depth, the implication would appear to be that competitive backstroke starts do not represent an appreciable risk of injury to the youngest swimmers. While it is certainly conceivable that a swimmer in this group could contact the pool bottom during the execution of a competitive backstroke start, from these data, this would appear to be unlikely. In terms of relative risk, given the greater depths attained during backstroke starts by the older swimmers, they appear to be at a greater relative risk than their younger counterparts as has been previously reported for forward starts from a block (Cornett et al., 2010, 2011).

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To our knowledge, this is the first study to describe the maximum depth of the head during competitive backstroke starts. As a result, there are no values for backstroke starts in the literature to which we can compare our data. The best comparisons that can be made are the data from Cornett et al. (2010) in which the maximum depth of the center of the head for freestyle, butterfly, and breaststroke starts during a competition in 1.22 m (4.0 ft) was measured. Cornett et al. found that freestyle starts were significantly shallower than butterfly and breaststroke starts. There is an assumption in competitive swimming that the head depth for backstroke starts is shallower than the head depth for starts for the other competitive strokes. To test this hypothesis, we chose to compare the head depth from backstroke starts with the head depths from freestyle starts.

The head depths for backstroke and freestyle starts were compared for each of the five age groups using an independent samples t-test. Each individual comparison was tested with an alpha level of 0.01 in order to maintain Type I error rate at the 0.05 level for the five comparisons. The head depths of the backstroke starts were significantly shallower than the head depths of the freestyle starts for the 8&U, 9-10, 11-12, and 13-14 age groups ($p < 0.001$), but there was not a significant difference between backstroke and freestyle starts for the 15&O age group.

In terms of safety, then, the significantly shallower head depths of backstroke starts displayed by the youngest four age groups suggests that backstroke starts represent the least amount of risk in comparison to the three other competitive strokes; however, the same cannot be said for the 15&O age group. The mean value for head depth for this group was similar for backstroke and freestyle (0.57 m and 0.54 m, respectively), and the deepest start analyzed was deeper for backstroke than for freestyle (0.88 m and 0.77 m, respectively). Thus, when considering head depth, it cannot be said that backstroke starts are safer than freestyle starts without clarification pertaining to the age of the swimmer. Because a significant difference was not detected between backstroke and freestyle starts (for the 15&O), the depth of the backstroke starts were then compared (independent samples t-test) with butterfly starts, the next deepest of the competitive strokes. The analysis revealed that there was not a significant difference ($p > 0.05$) between the maximum depth of the center of the head for 15&O backstroke and butterfly starts. Next, we compared the head depth of backstroke starts with the competitive stroke with the deepest head depths: breaststroke. The analysis (independent samples t-test) showed that the maximum head depth from breaststroke starts was significantly greater than for backstroke starts ($p = 0.037$). In terms of relative risk, from the perspective of head depth, greater risk is presented by forward block starts prior to breaststroke events (because of great head depth) than for starts prior to backstroke, freestyle, or butterfly events.

Head Speed at Maximum Head Depth

A number of studies have identified the impact speeds above which spinal injuries may be caused when the head strikes the surface perpendicularly: 0.60 ms^{-1} (sufficient momentum to dislocate the adult cervical spine; Stone, 1981 from Blanksby, Wearne, & Elliott, 1996), 1.20 ms^{-1} (sufficient momentum to crush the cervical spine; Stone, 1981 from Blanksby et al., 1996), 1.90 ms^{-1} (15% risk of serious neck and head injury; Viano & Parenteau, 2008), and 3.40 ms^{-1} (50% risk of serious neck and head injury; Viano & Parenteau, 2008). These later estimates of the threshold velocities are derived primarily from pendulum, linear impact, or inverted drop experiments using cadavers (Viano & Parenteau, 2008). Some are conducted with the cadavers in a supine position while others with the cadavers in the prone position. No mention of differences in injury outcomes was made specific to body position. We therefore assume that these estimates are appropriate for the present data (essentially supine) as well as for the data previously presented for forward starts from a starting block (Cornett et al., 2010). Table 2 represents the percentage of starts for each age group that exceed the critical thresholds. The point to be made is that nearly all (98%) of the backstroke starts filmed resulted in head speeds in excess of that suggested as capable of dislocating the adult cervical spine (> 0.6 ms^{-1}) and nearly three out of four starts filmed present sufficient momentum to crush the cervical spine (> 1.2 ms^{-1}) if an impact was to occur. It is important to point out here that none of our values are for vertical velocity. At maximum head depth, the swimmer is traveling in the horizontal plane prior to movement back toward the water surface. Head speed at maximum head depth, thus represents a risk of "potential" injury or "worst case" dependent upon the swimmers' trajectories.

Similar to what was observed with head depths, older swimmers appear to be at greater risk than younger swimmers because of their faster head speeds. Regression of head speed on age was statistically significant ($F = 15.31$, $p < 0.001$). The reason that older swimmers are moving faster is not clear. Head speed may be a function of body size, body mass, the ability to generate greater forces on the starting platform, and/or the ability to minimize resistive forces once in the water. Additional research is needed to define the important causal factors. Regardless of the specific mechanism, the conclusion is that older swimmers are moving faster at maximum head depth than the younger swimmers and thus are at a relatively greater risk.

Once again, due to the lack of research that has been conducted on the competitive backstroke start, we are limited in the comparisons we can make with data from the literature. When analyzing starts during a swimming competition in 1.22 m, Cornett et al. (2010) found that the head speed at maximum head depth was

Table 2 Percentage of Backstroke Starts Executed in 1.22 m During Competition With Head Speed at Maximum Head Depth Greater Than Proposed Thresholds for Head and Neck Trauma

Age Group	% > 3.4 ms^{-1} [a]	% > 1.9 ms^{-1} [a]	% > 1.2 ms^{-1} [b]	% > 0.6 ms^{-1} [b]
8&U	0	0	41.7	83.3
9-10	0	5.6	61.1	100
11-12	0	4.9	78.0	100
13-14	0	8.3	87.5	100
15&O	0	11.1	66.7	100
Combined	0	5.7	70.5	98.4

Values are percentages of starts with head speeds at maximum head depth greater than proposed thresholds for head and neck trauma from (a) Viano and Parenteau (2008) and (b) Stone (1981) as cited by Blanksby et al. (1996).

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significantly slower for breaststroke starts than for freestyle or butterfly starts. As a result, we chose to compare our head speed values for backstroke starts with those reported by Cornett et al. for breaststroke starts with an independent samples t-test for five different age groups (8&U, 9-10, 11-12, 13-14, and 15&O). We found that head speed was significantly slower for backstroke than for breaststroke starts for each of the five age groups ($p \leq 0.001$). Because the head speed at maximum head depth for breaststroke starts was shown to be significantly slower than for freestyle and butterfly starts, it is also possible to conclude that head speed is significantly slower for backstroke starts than freestyle and butterfly starts. Thus, when considering only head speed from the perspective of safety, backstroke starts appear to be safer than starts for the other competitive strokes, keeping in mind that nearly all starts analyzed exceed velocities predictive of injury potential.

Distance from the Wall at Maximum Head Depth

We included distance from the wall at maximum head depth as a dependent measure in our analysis because it has been used in previous literature pertaining to start safety (Blitvich et al., 1999; Blitvich, McElroy, Blanksby, Clothier, & Pearson, 2000). Additionally, USA Swimming rules stipulate that "minimum water depth for racing starts during practice and competition shall be measured for a distance 3 feet 3.5 inches (1.0 meter) to 16 feet 5 inches (5.0 meters) from the end wall" (USA Swimming Rules, 2011). Because of the complete lack of data describing backstroke starts, it is important to verify that backstroke starts (specifically maximum head depths) occur within this window. Furthermore, distance from the wall seems to be an important safety consideration given that pool bottoms are frequently sloped. The minimum and maximum values for distance from the wall at maximum head depth for backstroke starts were 1.04 and 5.25 m, respectively. Two out of 122 (1.6%) of starts analyzed had a distance from the wall at maximum head depth in excess of 5.0 m. These findings suggest that the rules pertaining to the distance from the starting wall at which water depth is measured should be reexamined.

Previous research has shown a significant relationship between age and the distance from the wall at maximum head depth for forward block starts (Cornett et al., 2010). We found a similar relationship between age and distance from the wall at maximum head depth for backstroke starts in that the older age group was significantly farther from the wall than the younger age group in eight of the ten possible pairwise comparisons. This finding is likely caused by greater height, strength, and/or skill in the older age groups rather than age per se. In addition, the older swimmers in these pairwise comparisons had significantly deeper maximum head depths than the younger swimmers. Greater distance from the wall is a logical outcome of a deeper start because it takes longer to reach maximum head depth and thus the swimmer has more time to move horizontally.

Conclusions

Catastrophic injuries fortunately occur very infrequently in the sport of competitive swimming. Statistics show that when major injuries occur they occur only once every other year or so and they almost exclusively occur during the execution of the competitive racing start. As a result, rules and regulations stipulate the minimum water depth that is permitted for the completion of forward racing starts from starting platforms and/or the pool deck. There is agreement by the various governing bodies that 1.22 m (4 ft) is the minimum safe water depth for forward block starts. However, currently these rules do not appear to apply to all racing starts, specifically those starts initiated from within the water.

As is true for any complex motor skill, the backstroke start has evolved over time. Early in the history of the backstroke start, swimmers did not dive deep because the intent was to begin swimming on the surface quickly after the start of the race. Thus, there was little reason to worry about the head depths attained during the execution of the backstroke start. In the late 1980s/early 1990s, the underwater dolphin kick gained widespread acceptance as a powerful tool to be used during the underwater phase of the backstroke start. This was shown to be so much of an advantage that rule changes were required to limit the extent to which swimmers could employ it. Swimmers would stay underwater for up to 30 to 35 m during a race while dolphin kicking, presumably to avoid wave drag. In order to do so, backstroke swimmers needed to dive deeper at the start of the race. Because there is no previous data for which to compare our current results we cannot conclude that head depths have changed. We can conclude, however, that maximum head depth for the backstroke start is not different than two of the three other competitive strokes for the older swimmers.

To extend this, then, we would conclude that older swimmers are at a greater relative risk executing a backstroke start than younger swimmers due to their greater maximum head depths and head speeds at maximum depth. When considering the relative risk of racing starts for the four competitive strokes on the basis of head depth, backstroke starts seem to be less risky than freestyle, butterfly, and breaststroke starts for the youngest four age groups. For older swimmers, however, there appears to be similar risk for backstroke, butterfly, and freestyle starts. This leads us to conclude that if swimmers are not permitted to execute freestyle or butterfly starts from a starting block due to shallow water, they should not be permitted to execute backstroke starts into shallow water either. As a result, we recommend that the governing bodies of swimming review rules for minimum water depths for backstroke starts and make them consistent with the rules for the other competitive strokes. Given that nearly all of the starts analyzed exceed velocities predictive of injury potential, the establishment of a minimum water depth for the execution of backstroke starts seems warranted.

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