Start Depth Modification by Adolescent Competitive Swimmers

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To expand upon previous studies showing inexperienced high school swimmers can complete significantly shallower racing starts when asked to start "shallow," 42 age group swimmers (6-14 years old) were filmed underwater during completion of competitive starts. Two starts (one normal and one "requested shallow") were executed from a 0.76 m block into 1.83 m of water. Dependent measures were maximum depth of the center of the head, head speed at maximum head depth, and distance from the starting wall at maximum head depth. Statistical analyses yielded significant main effects ($p < 0.05$) for start type and age. The oldest swimmers' starts were deeper and faster than the youngest swimmers' starts. When asked to start shallowly, maximum head depth decreased (0.10 m) and head speed increased (0.32 ms^{-1}) regardless of age group. The ability of all age groups to modify start depth implies that spinal cord injuries during competitive swimming starts are not necessarily due to age-related deficits in basic motor skills.

The safety risks associated with the execution of a competitive racing start are due to several factors. Some of these are under the swimmer's control and some are not. For example, the trajectory of the body upon leaving the starting block, the velocity at which the body is traveling, and the depth of the head during the trajectory are to a large extent determined by the swimmer or the physical body characteristics such as mass and strength. Block height and water depth, in contrast, are a function of the facility and regulatory requirements. If a swimmer comes into contact with the pool bottom, the severity of the injury that occurs is influenced by the swimmer's momentum, primarily a function of the velocity and mass of the swimmer. The swimmer's velocity is related to the forces generated by the swimmer while on the block, the swimmer's ability to reduce the resistive forces (streamline) once entering the water, and the height of the block above the water surface. The execution of a safe racing start therefore requires the swimmer to exhibit a complex blend of motor abilities, including such skills as static and dynamic balance, multiple axial movements, and ballistic locomotor skills.

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In a study reporting maximum head depth during completion of a competitive start, Blitvich, McElroy, Blanksby, Clothier, and Pearson (2000) found that elite junior competitive swimmers (age 15.3 ± 2.4 yrs), who were not given any direction as to the depth of their start, completed significantly shallower starts in a 1.2 m water depth than in a 2.0 m water depth. We recognize this as a particularly important finding as it demonstrates that experienced adolescent swimmers have the motor and perceptual abilities needed to detect and modify head depth during a competitive start when presented with different starting end water depths. We repeated this experiment using experienced competitive swimmers (age 20.1 ± 1.2 yrs) and three different starting depths (1.53 m, 2.14 m, and 3.66 m; Cornett, White, Wright, Willmott, & Stager, 2011a) to better understand the relevance of previous research conducted in diving wells. Not surprisingly, in accordance with the findings of Blitvich et al., we found that these older swimmers executed the deepest starts in the deepest water without receiving direction or instruction.

The work of Blitvich et al. (2000) and Cornett et al. (2011a) demonstrated that experienced swimmers adjust the depth of their start when and where appropriate, but it was unclear whether or not inexperienced swimmers also possessed the capability to do so. We compared the ability of novice high school (14.8 ± 1.1 yrs) and experienced collegiate aged swimmers (20.1 ± 1.2 yrs) to modify head depth upon "request" (White, Cornett, Wright, Willmott, & Stager, 2011) by having the swimmers execute two starts. The first start was a "typical" racing start. Prior to the second start, the swimmers were directed to perform a "shallow" start. Initially, we thought the ability to modify depth was a skill that required time and experience to develop. We found that this was not the case. Our results showed that, upon request, both novice and experienced competitive swimmers were able to decrease maximum head depth and they did so to a similar extent. The major caveat of the findings was that while statistically each sample of swimmers demonstrated the capability to modify depth, not all of the novice swimmers were observed to do so. It is not clear if this later observation was due to individual differences in age, experience level, or a combination of the two.

Nevertheless, the collective conclusions drawn from the relevant research is that swimmers fifteen years and older appear to have the motor and perceptual motor skills necessary to modify head depth. At this point it remains unclear whether or not younger children possess similar capabilities. A child's progression toward "mature motor abilities" "depends on a variety of experiential factors, including opportunities for practice, encouragement, and instruction in an environment conducive to learning" (Gallahue & Ozmun, 2006, p. 186). The achievement of the "mature level" in fundamental motor skills before the age of seven is a matter of disagreement among motor development researchers (Gallahue & Ozmun, 2006; Haywood & Getchell, 2009; Langendorfer & Roberton, 2002). These same experts do agree that refinement of these skills occurs across childhood and adolescence as improvements in perceptual abilities are made and additional focused practice continues. Thus, it seems that children may have the requisite fundamental motor skills, but whether or not they can produce the desired sport skill behavior to modify start depth when requested to do so remains undetermined.

The purpose of this study was to extend the current findings in this area by examining the capability of younger, competitive swimmers to modify maximum head depth during the execution of racing starts. A secondary purpose of the project was to examine the effect of age on competitive racing start parameters.

Method

Participants

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 and his/her guardian. The participants were members of a competitive swim club in the eastern United States and were grouped according to USA Swimming age classifications for analysis: 10 years and under (10&U; n = 14), 11–12 years (11–12; n = 10), and 13–14 years (13–14; n = 18). The primary research question involved an independent variable (start type; normal or shallow) that was a repeated measures factor. As a result, no attempt was made to control for sex, height, or mass between the age groups. Participant characteristics for the groups are displayed in Table 1.

Procedures

Data collection took place in an aquatic facility with a 6-lane, 50-m competition swimming pool. A bulkhead was l located at mid-pool in four of the lanes. A portable starting block was custom designed for the project (Adolph Kiefer and Associates, Zion, IL) with a platform height of 0.76 m at an angle of 10° from horizontal was placed on the bulkhead and swimmers completed starts from this position. The water depth was 1.83 m at the location in which swimmers entered the water.

All subjects performed two competitive starts from the starting block. For the first start, swimmers were asked to complete a racing start and a subsequent freestyle sprint across the pool (normal). For the second start, however, the swimmers were requested to execute "a shallow start" followed by a freestyle sprint across the pool (shallow). 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).

Video Recording

The underwater portion of the dive start was videotaped using a Canon GL2 digital video camcorder (Canon Inc., Tokyo, Japan) placed in a sealed housing unit (Ikelite Underwater Systems, Indianapolis, IN) and mounted on a heavy tripod (Hercules model, Quick-Set Inc., Northbrook, IL) placed on the bottom of the pool. The camera was aligned perpendicular to the direction of the dive, and a Canon WD-58

Table 1   Subject Characteristics

Age Group	N	Age (yr)	Mass (kg)	Height (m)
10&U	14 (6-male, 8-female)	7.86 ± 1.29	30.94 ± 6.65	1.29 ± 0.10
11–12	10 (4-male, 6-female)	11.30 ± 0.48	42.94 ± 6.09	1.48 ± 0.06
13–14	18 (5-male, 13-female)	13.50 ± 0.51	53.97 ± 6.31	1.62 ± 0.06

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

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 dive. Camera zoom and focus were adjusted underwater once the tripod/camera unit was in place. An Opticis Optical IEEE1394 FireWire Repeater (M4-100; Opticis North America, Inc., Chatham, Ontario, Canada) extended the range of the video cable to 30 m and enabled the video signal to be input directly to a Gateway (model #: M675, Gateway Inc., Irvine, CA) laptop computer at the poolside. The video signal was captured using SIMI Motion software (zFlo Inc., Quincy, MA).

Calibration

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

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

Video Analysis

Following the calibration of the dive area, the competitive dives were recorded and analyzed using SIMI Motion. In each dive, the center of the participant's head was manually digitized from the frame in which it was first visible below the surface through to 10 frames after the instant at which qualitative analysis of the video suggested that the head had reached its maximal depth and was beginning to move back towards the surface. The (x,y) position of the head in each frame was calculated by SIMI Motion using the 2D DLT procedure.

Data Analysis

A two-way (2 × 3) mixed design ANOVA for start type and age group was utilized to test for differences for the three dependent measures (maximum depth of the center of the head, head speed at maximum head depth, and distance from the wall at maximum head depth). When a significant F-ratio was obtained for the age group variable, all pairwise comparisons were conducted using Tukey's HSD procedure. When the ANOVA test revealed significant interactions, simple effects analyses were conducted using methods previously established (Keppel & Wickens, 2004). For all analyses reported below, an alpha level of 0.05 was used to determine statistical significance.

Results

The values for the normal and shallow trials for all three age groups are presented in Table 2. The two-way (2×3) mixed design ANOVAs for maximum depth of the center of the head, head speed at maximum head depth, and distance from the wall at maximum head depth yielded significant main effects for start type, $F(1,39) = 16.65$, p < 0.001, Partial $\eta^2 = 0.30$; $F(1,39) = 12.94$, p = 0.001, Partial $\eta^2 = 0.25$; $F(1,39) = 32.46$, p < 0.001, Partial $\eta^2 = 0.45$, respectively, and age group, $F(2,39) = 5.42$, p = 0.008, Partial $\eta^2 = 0.22$; $F(2,39) = 16.59$, p < 0.001, Partial $\eta^2 = 0.46$; $F(2,39) = 26.46$, p < 0.001, Partial $\eta^2 = 0.58$, respectively.

The significant main effects for start type indicated that when asked to execute a shallow start, swimmers performed starts that had shallower maximum depths of the center of the head (Figure 1), faster head speeds at maximum head depth (Figure 2), and shorter distances from the wall at maximum head depth (Figure 3). The significant main effects for age group, and the pairwise comparisons that followed, indicated that maximum depth of the center of the head was deeper for the 13–14 age group than the 10&U age group (Figure 1), head speed at maximum head depth was faster for the 11–12 and 13–14 age groups than the 10&U age group (Figures 2), and distance from the wall at maximum head depth was farther for the 13–14 age group than the 11–12 and 10&U age groups, and for the 11–12 age group than the 10&U age group (Figures 3). There was not a significant start type by age group interaction (p > 0.05) for maximum head depth which indicated that swimmers in the 10&U, 11–12, and 13–14 age groups did not differ in their ability to modify maximum head depth.

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

| Age Group	Requested to Dive Shallow?	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		
10&U	No	14	0.20	0.50 ± 0.20	0.82	1.69 ± 0.58	3.29 ± 0.73
	Yes	14	0.14	0.35 ± 0.18	0.74	1.89 ± 0.83	3.00 ± 0.43
11-12	No	10	0.38	0.58 ± 0.24	1.19	2.37 ± 0.55	3.98 ± 0.37
	Yes	10	0.37	0.45 ± 0.07	0.55	2.86 ± 0.86	3.47 ± 0.25
13-14	No	18	0.41	0.61 ± 0.11	0.83	2.75 ± 0.51	4.36 ± 0.42
	Yes	18	0.32	0.56 ± 0.14	0.81	3.08 ± 0.49	4.04 ± 0.36
Combined	No	42	0.20	0.56 ± 0.18	1.19	2.31 ± 0.71	3.91 ± 0.70
	Yes	42	0.14	0.46 ± 0.17	0.81	2.63 ± 0.88	3.56 ± 0.58

Values are means ± standard deviation. All values are measured at the center of the head. Statistical analyses yielded significant main effects (p < 0.05) for instruction (request to dive shallow) and age group indicating that when asked to execute a shallow start, swimmers performed starts that had shallower maximum head depths, faster head speeds at maximum head depth, and shorter distances from the wall at maximum head depth. Pairwise comparisons between the age groups demonstrated significant differences between the following: 10&U and 13–14 for depth, speed, and distance, 10&U and 11-12 for speed and distance, and 11–12 and 13–14 for distance.
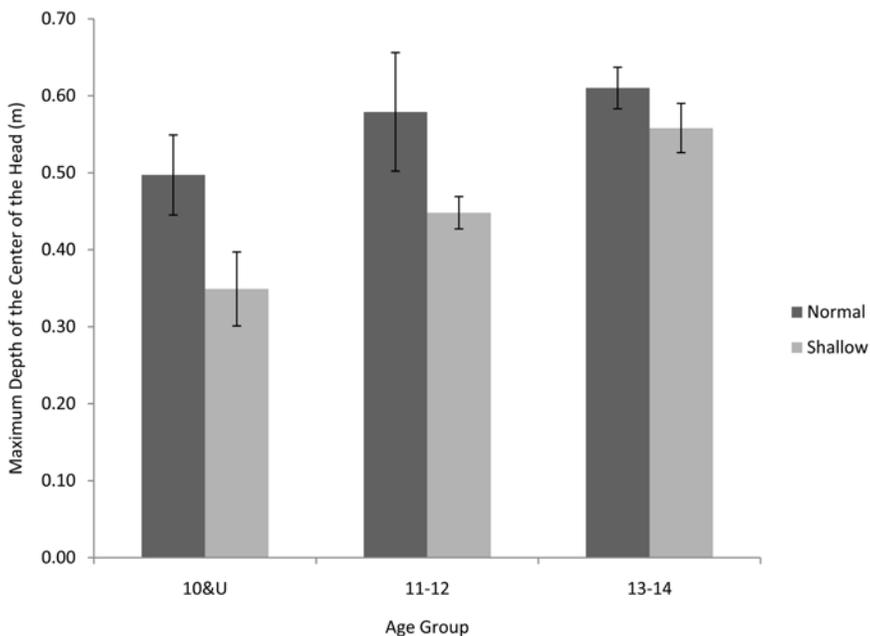
Figure 1 — Maximum depth of the center of the head (m) as a function of age group and start type. The two-way ANOVA revealed significant main effects for age group and start type ($p < 0.05$), and the post hoc tests indicated that maximum depth of the center of the head was deeper for normal starts than shallow starts and for the 13–14 age group than the 10&U age group. Error bars are 1 SE.
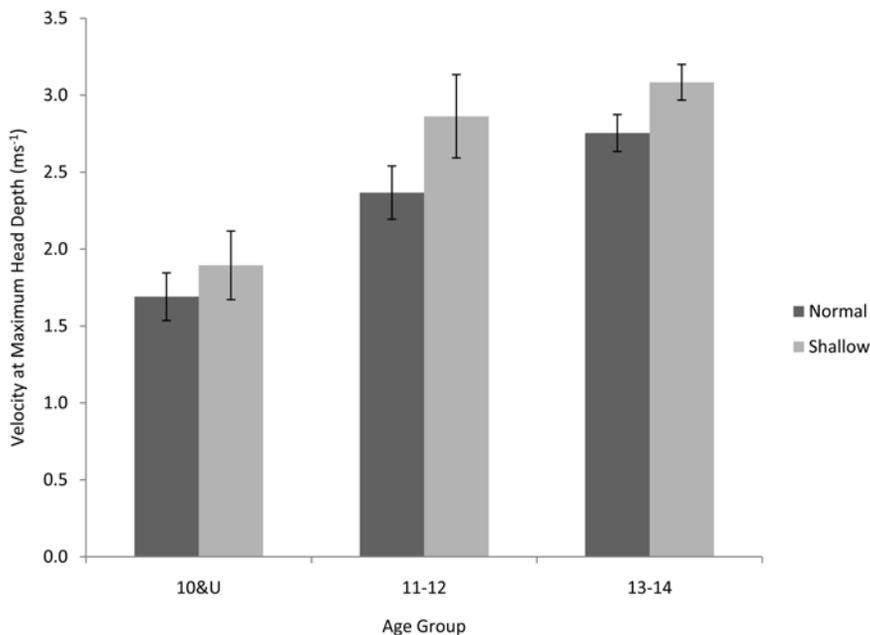
Figure 2 — Head speed at maximum head depth (ms^{-1}) as a function of age group and start type. The two-way ANOVA revealed significant main effects for age group and start type ($p < 0.05$) and the post hoc tests indicated that head speed at maximum head depth was faster for shallow starts than normal starts and for the 11-12 and 13-14 age groups than the 10&U age group. Error bars are 1 SE.
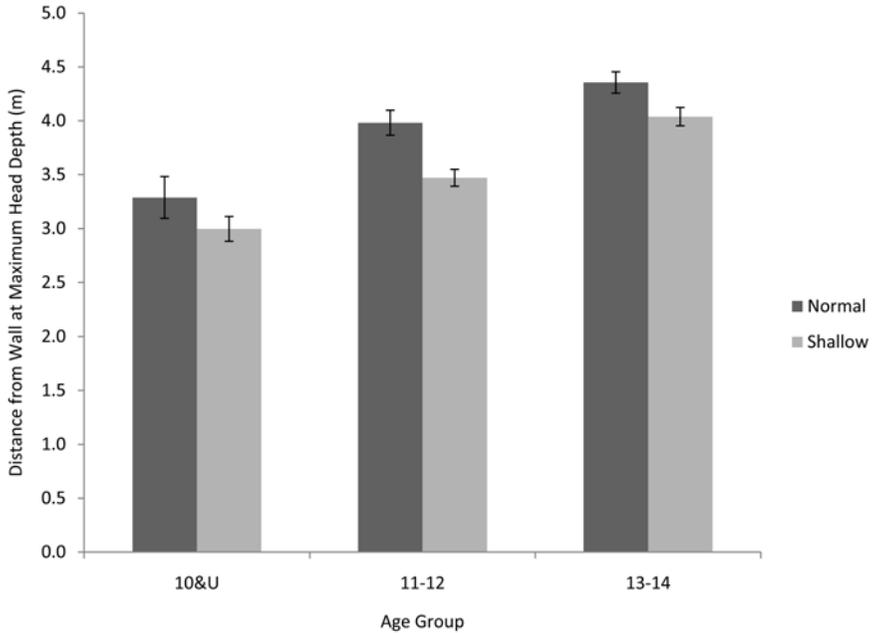
Figure 3 — Distance from the wall at maximum head depth (m) as a function of age group and start type. The two-way ANOVA revealed significant main effects for age group and start type ($p < 0.05$), and the post hoc tests indicated that distance from the wall at maximum head depth was farther for normal starts than shallow starts, for the 13–14 age group than the 11–12 and 10&U age groups, and for the 11–12 age group than the 10&U age group. Error bars are 1 SE.

Discussion

The purpose of this study was to examine the ability of young, competitive swimmers to modify the depth of their racing start and to determine whether or not the ability to control depth is a function of the swimmers' age. The main findings were that competitive swimmers when requested to "start shallow" were able to do so and the ability to modify start depth was not different across age groups.

Maximum Depth of the Head and a Request to "Start Shallow"

We were concerned with two questions pertaining to what occurs when swimmers are asked to execute a shallow start. First, can all competitive age group swimmers execute a shallower start when asked to do so? And second, if they are able to do so, are older swimmers better at modifying depth than the younger swimmers? The answer to the first question, as evidenced by the significant main effect for start type, is "yes." When asked to execute a shallow racing start, competitive age group swimmers as a group performed starts with a shallower maximum depth of the center of the head. The answer to the second question, as evidenced by the lack of a significant age group by start type interaction, is "no." The swimmers in the three age groups were not different in their capability to control start depth.

These findings are consistent with results reported previously when novice high school aged swimmers (14.8 ± 1.1 yrs) and experienced collegiate aged swimmers (20.1 ± 1.2 yrs) were asked to execute a shallow start (White et al., 2011). Statistically, both groups of swimmers were able to decrease the maximum depth of the center of the head in response to being asked to execute a shallow racing start and the groups were not different in their ability to modify depth. The major difference between the present study and the previous report has to do with the age of the swimmers asked to complete shallow racing starts. The oldest swimmers who participated in the present study were preadolescents and adolescents and were younger than the high school swimmers utilized by White et al. While it is natural to suppose that older swimmers would be better than younger swimmers at modifying start depth, the lifespan motor development literature disagrees on the evidence for this outcome. Some text authors claim fundamental motor skills are "mature" by school age (Gallahue & Ozmun, 2006), while other motor development researchers strongly disagree for some skills. For example, in the skill of overarm throwing for force, advanced developmental levels are infrequently observed until middle adolescence (Halverson, Roberton, & Langendorfer, 1982).

Clearly, the execution of a safe racing start requires a complex blend of motor capabilities (such as static and dynamic balance, multiple axial movements, and ballistic locomotor skills) in addition to perceptual abilities (such as depth perception, figure ground perception, and visual acuity). While there is a range of ages described for the onset of the building blocks of sport skills, the degree of attainment by children ages eight years or earlier is a matter of strong disagreement in the motor development literature (Gallahue & Ozmun, 2006; Langendorfer & Roberton, 2002). Rudimentary perceptual abilities show rapid improvements by three years of age and intermediate levels by 8-12 years of age (Gallahue & Ozmun, 2006). Children often do not demonstrate mature or advanced perceptual-motor profiles (the integration of motor and perceptual abilities such as body awareness, spatial awareness, directional awareness, and temporal awareness) until middle adolescence (Haywood & Getchell, 2009). Whether the change in these foundational capabilities translates into consistent control of a complex sport skill such as a racing start has not been documented in the literature prior to this study.

Because the capability to execute a safe racing start from a standard starting block incorporates all of these skills, given the individual variability in timing of motor, perceptual, and perceptual-motor development, it was not known whether the competitive swimmers in this study would differ across age groups in their ability to modify start depth. The current study is important because it does show that the capability to modify the maximum depth of the center of the head is not specific only to the highly experienced collegiate swimmers or the inexperienced high school swimmers studied by White et al. (2011) or the elite junior swimmers filmed by Blitvitch et al. (2000). Instead, our study demonstrates that the capability to modify the maximum depth of the center of the head is present in competitive swimmers regardless of age.

It is critical for readers to note that not all swimmers videotaped in this study made modifications to their starts when asked to do so. The percentage of swimmers who were able to modify maximum depth of the center of the head on request was 86% for the 10&U age group, 70% for 11-12 age group, and 72% for 13-14. When all age groups were combined, 76% of all swimmers were able to successfully

modify the maximum depth of the center of the head. This finding is similar to that of White et al. (2011) who reported that 77% of inexperienced high school swimmers (and 100% of collegiate swimmers) successfully modified the maximum depth of the center of the head on request. The important point to be made is that while each group of swimmers statistically decreased head depth when requested to start shallow, as individuals, other than the experienced collegiate swimmers, they could not always be relied upon to do so. It was not clear why the percentages decreased across age group. One might have predicted that the percentage of swimmers able to modify their starts would increase across age group, not decline. Further investigation into this variability needs to be conducted.

Head Speed at Maximum Head Depth and a Request to "Start Shallow"

Head speed at maximum head depth increased to a similar extent in swimmers in the 10&U, 11–12, and 13–14 age groups when requested to dive shallow. Once again, this is consistent with previous comparisons for "normal" and "shallow" starts (White et al., 2011). The increase in head speed at maximum head depth when swimmers are instructed to dive shallow is a logical outcome, as the head has traveled less distance through the water both vertically and horizontally and has therefore lost less momentum due to the drag forces of the water on the body (Cornett, White, Wright, Willmott, & Stager, 2011b).

Head speed at maximum head depth is an important issue from the perspective of potential injuries resulting from an impact. Ninety-two percent of the starts evaluated in the current study resulted in head speeds at maximum depth above 0.61 ms^{-1}, an estimated minimum velocity threshold for cervical dislocation upon impact (Stone, 1981 from Blanksby, Wearne, & Elliott, 1996). Head speeds at maximum head depth exceeded 1.9 ms^{-1} (a 15% risk of catastrophic injury; Viano & Parenteau, 2008) in 77% of starts and 3.4 ms^{-1} (50% risk of catastrophic injury for inverted drops on a rigid surface; Viano & Parenteau, 2008) in 6% of starts. It is important to point out here that none of our values are for vertical head velocity. At maximum head depth, the swimmer is traveling in the horizontal plane and is about to move back toward the water surface. Nevertheless, head speed at maximum depth represents a risk "potential" value, probably a conservative estimate of the head speed possible if the athlete had continued toward the pool bottom. Additional research is needed if valid estimates are to be made of the potential speeds swimmers attain at various depths following a racing start.

Distance From the Wall at Maximum Head Depth and a Request to "Start Shallow"

Distance from the wall at maximum head depth decreased to a similar extent in swimmers in the 10&U, 11–12, and 13–14 age groups when they were requested to start shallow. The decrease in distance from the wall was correlated with the decrease in maximum depth of the center of the head (r = 0.28, p = 0.044). This finding is consistent with Blitvich et al. (2000) and White et al. (2011), which both displayed significant decreases in distance from the wall with decreasing maximum depth of the center of the head. The decrease in distance from the wall is likely

a natural consequence of a shallower start. If swimmers execute shallower starts by beginning movement toward the surface earlier, the distance from the wall at which the maximum depth of the center of the head occurs would also decrease (Blanksby et al., 1996).

The Effect of Age on Racing Start Parameters

In addition to analyzing the effects of a request to start shallow on maximum depth of the center of the head, a secondary aim of the project was to examine the effect of age on competitive racing start parameters. Swimmers in the older age groups performed starts that were deeper, faster, and farther from the wall at maximum head depth. The greater mass and height of the older swimmers (all pairwise age group comparisons for mass and height were statistically significant, $p < 0.01$) confounds the statistical analysis of differences due to age group.

We performed partial correlations on our data in order to gain a better understanding of the effect of age on racing start parameters while controlling for mass and height. We found that age and head speed at maximum head depth were significantly related ($r = 0.37$, $p = 0.018$) even after the effects of mass and height were removed. It is difficult to explain the exact nature of this relationship unless age is strongly associated with previous experience performing racing starts. Previously, Cornett et al. (2011b) suggested that the head speed at maximum head depth attained by the swimmer is a likely to be a function of the size and skill of the athlete. While some fundamental movement skills differ in their age to maturity, these skills are reported to be capable of further refinement by experiential factors such as practice, encouragement, and instruction (Gallahue & Ozmun, 2006; Haywood & Getchell, 2009; Langendorfer & Roberton, 2002). White et al. (2011) detected a significant relationship ($r = 0.64$, $p = 0.01$) between experience and head speed at maximum head depth while controlling for age, height, and mass in high school and collegiate swimmers. It was suggested that the most likely explanation was that more experienced swimmers were more skilled, had "cleaner" entries, and maintained more momentum through the air-water interface than younger and less experienced swimmers.

We suggest a similar explanation for our significant partial correlation between age and head speed. The older swimmers in our sample were likely more experienced than the younger swimmers and as a result had greater skill, which enabled them to enter the water "cleaner" and thus maintain more momentum. This claim is speculation on our part as we did not quantify "experience" in this study and thus cannot verify our assumption with empirical data in this study. More research is required to fully understand the interplay between start depth, start speed, age, skill, height, and mass.

Because the current study did not include a control group of noncompetitive swimmers or matched pairs with less swimming experience and it only sampled a single trial of each type, we had limited ability to study several key mechanisms. A control group with established differences in swimming (and presumably, diving) experience could have allowed us to verify our speculation about the role of experience. Equally importantly, multiple trials of each type of start could have allowed us to investigate the role of variability across age groups. Future studies should examine these questions.

Conclusions

When stratified by standard competitive age groups, swimmers can modify the depth of their start when requested to do so. A general assumption has been that younger swimmers are not able to control head depth due to inexperience and/or less well-controlled motor coordination, but our findings demonstrate otherwise. Our results can be interpreted to show that even the swimmers within the youngest age group demonstrated a considerable measure of movement control through their capability to modify depth. Because we observed swimmers in each age group who did not execute shallower starts upon request, we suggest that there is a measure of interindividual variability and uncertainty within each age group and that the capability to modify depth may not be dependent upon age per se. Coupled with the findings of our previous research, we suggest that experience, or rather inexperience, may be equally important in this regard.

The findings of this study further reinforce the data showing older swimmers attaining deeper depths, faster speeds, and longer distances during a start as compared to younger swimmers. The majority of starts we observed resulted in head speeds at maximum head depth great enough to cause cervical spinal injuries. This fact, in combination with the observed relationship between age and head speed, leads us to conclude that the older inexperienced swimmers are at greater risk of injury while executing racing starts in shallow water. We emphasize, however, that the uncertainty observed needs to be considered carefully in each age category. Due to a general lack of information on these aspects of the safety of racing starts additional research definitely appears warranted.

Acknowledgments

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