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Head Depth and Head Speed During Competitive Backstroke Ledge Starts

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Authors

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Abstract

Recently, a commercially available starting 'ledge' designed to reduce foot slippage during the execution of the backstroke start was introduced in competitive swimming. For the purpose of identifying potential safety consequences, the present study investigated the effect of ledge use on head depths, speeds, and distances in backstroke starts of athletes with no prior or only novice familiarity of the ledge. Competitive backstroke starts were performed with and without ledges by high school-aged (14.5 to 19.2 yr, $N = 61$) swimmers in 1.52 m of water during a closed testing session. A SIMI Reality Motion System in a calibrated space using three cameras was employed for filming starts. Dependent measures were initial head height (Y_{set}), distance from wall at entry (X_{entry}), entry angle ($Angle_{entry}$), horizontal velocity at head entry ($XVel_{entry}$), resultant velocity at entry ($ResVel_{entry}$), maximum depth of the center of the head (Y_{mhd}), resultant velocity at maximum head depth ($ResVel_{mhd}$), and distance from the wall at maximum head depth (X_{mhd}). The ledge (L) condition showed significant increases compared to the non-ledge (NL) condition in X_{entry} (L 1.61 ± 0.59 m, NL 1.50 ± 0.53 m, $p < .001$), $ResVel_{entry}$ (L 3.44 ± 0.97 m·s^{-1}, NL 3.08 ± 1.00 m·s^{-1}, $p < .001$), $Angle_{entry}$ (L 43.13 ± 16.97°, NL 39.66 ± 18.11°, $p = .030$), X_{mhd} (L 4.18 ± 0.58 m, NL 4.09 ± 0.63 m, $p = .008$), and Y_{mhd} (L 0.54 ± 0.21 m, NL 0.49 ± 0.18, $p < .001$). Backstroke starts using the ledge modestly affected 5 of 8 dependent measures in a direction arguably associated with an increased risk to the novice swimmer.

Keywords: swimming, water safety, racing starts, athlete injury, risk assessment, backstroke start

Introduction

When catastrophic injuries occur in competitive swimming, they are commonly associated with swimmers coming in contact with the pool bottom following the execution of racing start (Mueller, 2008). The injuries that swimmers incur upon impact are related to hyperflexion, vertical compression, and/or hyperextension of the cervical vertebrae and, as is true for all other diving injuries, impact with the pool bottom has resulted in para- or quadriplegia (Albrand & Walter, 1975). This is clearly related to the head velocity that proficient swimmers achieve (4 to 6 m·s^{-1}) when executing racing starts from a starting block into a pool (Cornett, White, Wright, & Stager, 2014). As such, according to the National Federation of State High Schools Association (NFHS) and the National (USA) Collegiate Athletic Association (NCAA) regulations, pools must minimally be 1.2 m deep at the starting end (NCAA Rules and Regulations) for starting blocks to be used. Given that swimmers are entering the pool at approximately 4 m·s^{-1} into a pool depth of 1.2 m, if a swimmer initiates a technical error during the execution of a front start, once entering the water surface, there is very little time available (less than 250 milliseconds) for the swimmer to alter the dive trajectory as a means to avoid a collision with the pool bottom. Due to the speeds and consequences described, there is reason to investigate the safety of swimmers executing racing starts into shallow water.

Anecdotal evidence suggests that swimmers performing a start from in the water, in comparison to a starting block, are less susceptible to traumatic injury. However, it has been empirically demonstrated that proficient swimmers performing the modern backstroke start (i.e., a start performed by pushing off of the wall of the pool) can reach head velocities consistent with vertebral injury upon impact (Cornett, White, Wright, Wilmott, & Stager, 2011). Furthermore, the backstroke start carries the additional risk of the swimmer being blind to the bottom of the pool, thereby generally eliminating that small amount of time with which a swimmer could recognize their trajectory and avoid impact with the bottom of the pool.

Because of the flat wall design of many pools and potentially slick touchpad surfaces, there exists the real possibility for swimmers' feet to slip during the backstroke starts. How often this occurs has not been reported. In order to prevent swimmers' feet from slipping during starts, a temporary ledge (79 cm x 8 cm x 2 cm at base with 10° slope; see Barkwell and Dickey, 2017) coated with an anti-slip surface was introduced into the commercial market in September 2014. The international governing body for swimming referred to as the Fédération Internationale de Natation (FINA) and USA Swimming, the United States' governing body for swimming, each approved the ledge for competition usage shortly thereafter. The NCAA ultimately followed and allowed use starting in the 2015-2016 school year (NCAA, 2015), and the National Federation of State High School Associations (NFHS) had been petitioned to allow the ledges for competition starting in the 2017-2018 school year, ultimately deciding against implementation of the device (NFHS, 2018). Because most national and international competitions take place in pools with a minimum depth of at least 2 m at the starting end (in accordance with FINA's regulations, de Natation, F. I., 2015 FINA Swimming Rules) an aberrant or deeper start trajectory does not appreciably increase the risk of a collision with the bottom of the pool during FINA sanctioned events. This is not true for high school and age group competitions in the USA which can take place in 1.22 m of water. Current data describing how the 'ledge' affects the trajectories and velocities of backstroke starts of adolescent and post-adolescent swimmers are lacking. However, the manufacturers' advertisements and user's manuals claim that using the ledge increases the angle between the swimmer's body and the surface of the water during the start. These assertions are intertwined with wholly unsupported insinuations of increased performance, claiming that a greater starting angle allows the swimmer's feet to make less contact with the water during the start and creates a longer jump trajectory (Gajanan, 2016). This seems to be, at least partially, substantiated by the recent study by Barkwell and Dickey (2017) describing starts executed with the ledge by "high-level backstroke swimmers." In contrast, novice swimmers have been shown to be less predictable and perhaps at greater risk in shallow water as compared to experienced elite swimmers (Cornett, Naganobori, & Stager, 2012).

If the claim of an increased starting angle is in fact true, it results in increased maximum head depth and head velocity at maximum head depth, thereby increasing the risk of catastrophic collision with the bottom of the pool. As inconsistency in start depth is observed in novice athletes, increasing the athlete's starting angle would compound their already increased risk of severe head or neck injury (Cornett et al., 2012). What is absent from the user's manuals from major manufacturers of the backstroke ledge is the concept of safety, insofar as the adequate, or necessary water depth for the safe use of these devices. Therefore, as a means of stratifying risk, the questions posed by the current study as they relate to novice use of the backstroke ledge are:

i. Does the ledge alter the swimmer's entrance angle in such a way that it is less acute relative to the water's surface?
ii. Does the ledge result in greater head velocity at maximum head depth?
iii. Does the ledge cause the underwater trajectory (i.e., maximum head depth) to be deeper when compared to racing starts performed without the ledge?

In line with anecdotal testimony, it was hypothesized that the ledge would make the swimmer's entrance angle less acute relative to the water's surface (or closer to the vertical perpendicular) and would result in the swimmer reaching a greater maximum head depth upon water entry and potentially a greater velocity at maximum head depth. These changes, regardless of their magnitude, would be interpreted as representing 'increased risk' especially to the less predictable, less skilled, adolescent swimmer executing a racing start in shallow water.

Method

Participants

Prior to initiation of the study, the project was approved by the University's Human Subjects Committee. Informed consent and parent/guardian assent were obtained from each participant after written and verbal explanations of the study were provided. Eighty swimmers who were members of their local high school competitive swim team were recruited for the project. Data from sixty-one swimmers were considered usable for analysis. The remainder were unable to complete a proficient backstroke start as judged by a USA Swimming certified coach. Previous literature has not reported discrepancies in start characteristics between sexes (Cornett, White, Wright, Willmott, & Stager, 2010; Counsilman, Counsilman, Nomura, & Endo, 1988) therefore data for the girls and boys were pooled and no discrimination by sex was made. Participant characteristics are displayed in Table 1.

Experimental Procedures

The testing took place in a natatorium 22.86 m in length with a starting end depth of 1.53 m. No other activities took place in this facility during the testing. Swimmers were permitted a 15 to 20-minute warm-up that included swimming lengths of the pool and performing backstroke starts without use of the backstroke starting device. Following the warm-up, swimmers were asked to perform four backstroke starts (the first two starts without the backstroke starting device and the second two starts with the starting device). Prior to testing, no swimmer had experience using a starting ledge. Following the first two starts swimmers were given a demonstration that provided instructions to operate the backstroke starting device. They were also given the option to place the device at an adjustable water depth of their choice. The reason for this decision was that we were interested in examining how swimmers would use this device upon initial exposure with minimal instruction and/or guidance. Swimmers mimicked a competitive situation and were asked to place their feet, then given a verbal command, "take your marks," then an audio signal (portable Daktronics starter, Brookings, SD) initiated the start. Swimmers followed each start with backstroke (back crawl) midway across the pool (approximately 15 m).

Backstroke Starting Device. The backstroke starting device utilized in this study was the commercially available Colorado Timing Systems Backstroke starting device (Colorado Timing, Loveland, CO). The device is secured via nylon straps to the existing starting block at the edge of the pool deck. The device is a molded non-slip composite material that measures 65 cm by 8 cm and features a 10° angle for foot placement. Swimmers pull the device from a tethered mechanism that is located on deck then place the device over the starting pad, then place their feet on the device to hold it in place. Upon completion of the backstroke start the device automatically retracts into a mechanism on the pool deck to allow for removal of the ledge from the pool wall surface.

Digital Video Recording. Three digital cameras (Basler scA640-120gc, Ahrensburg, Germany) were used for video recording. Each camera was fitted with a manual lens (FUJIFILM Mega Pixels dv3.4x3.8SA-1, Edison, NJ) and placed upon a tripod (Monfrotto 055, South Upper Saddle River, NJ). One camera was placed above water (on the pool deck, perpendicular to the plane where starts were being performed approximately 2.5 m from the starting end wall) and two cameras were placed below water (one perpendicular to the plane where starts were being performed 2.5 m from the starting end wall and the second one in the same plane 7.0 m from the starting end wall). The camera placement is described in Figure 1. Underwater cameras were protected in custom built underwater housings (Sexton Co., Salem, OR). Cameras were synchronized and video was captured at 120 Hz (0.3 MP; 640 x 480 pixels) using SIMI Reality Motion systems software (Simi Motion Inc. Los Angeles, CA).

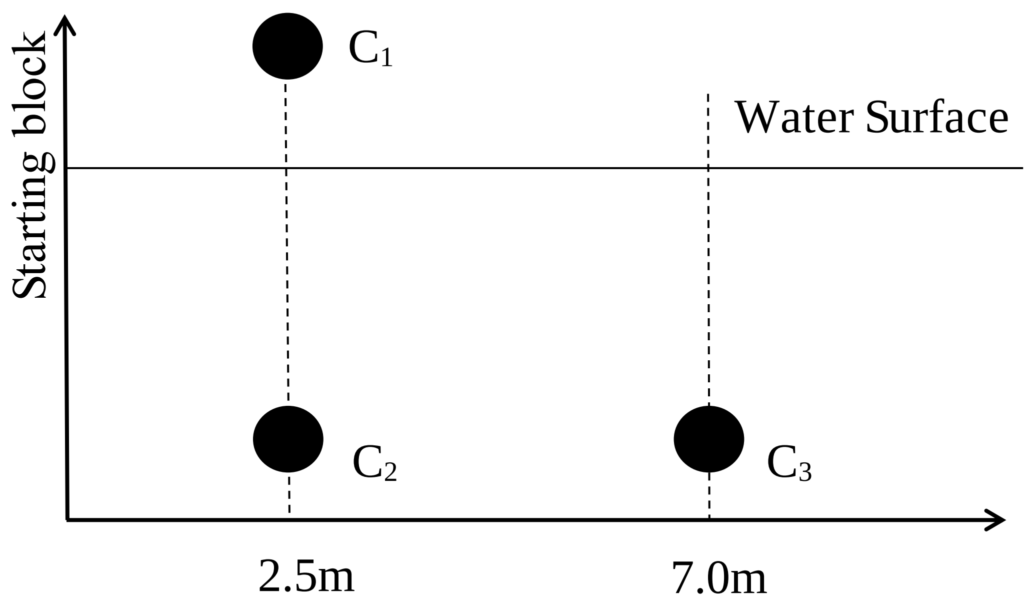

Figure 1 - The placement of the 3 cameras used to create the viewing frame. Cameras 1 (C1) and 2 (C2) were placed 2.5m from the starting end wall, while Camera 3 (C3) was placed 7m from the starting end. C1 was placed above the water surface level, with C2 and C3 were submerged to capture the entirety of each backstroke start.

Calibration. The spatial areas above and below water in which starts were performed were calibrated using the 2D direct linear transformation procedure in SIMI Reality Motion software. A custom-built 1 m x 3 m aluminum frame was placed vertically in line with the center of the starting area perpendicular to the side of the pool at known distances above (using foam boards to float in place) and below the surface of the water (by suspending the frame from the foam boards). During the period of video capture for the purpose of calibration, the frame structure was secured and immobile. The frame was painted black and thirty yellow spheres (marker balls) approximately 0.05 m in diameter were located at precise intervals around the frame. The two underwater cameras were used to expand our field of view because we were unsure where each swimmer would reach maximal head depth. Each camera view consisted of shared points thus allowing us to overlap the field of calibrated space. It should be noted, however, that video analysis displayed a majority of swimmers reached maximal head depth within the calibrated space of camera 2 (located approximately 2.5 m from the starting end wall).

Digital Video Analysis

Manual and pattern-matching digitizing procedures in SIMI Reality Motion were used to analyze captured video clips. Head height during the 'set position' (Y_{set}), distance from the wall at head entry (X_{entry}), resultant velocity at head entry ($ResVel_{entry}$), maximum depth of the center of the head (Y_{mhd}), head speed at maximum head depth ($ResVel_{mhd}$), and the distance from the wall at maximum head depth (X_{mhd}) were measured for each trial. The mean of the values for the two starts was used as the respective value for each swimmer. Degrees of $Angle_{entry}$ was calculated from the inverse cosine of the quotient of X_{entry} and $ReslVel_{entry}$. In each start the center of the swimmer's head was digitized from initial starting position through the instant at which the software suggested the head had reached maximal depth. Measures of dependent variables recorded from the digitized video are depicted in Figure 2. Fourteen swimmers were unable to perform adequately, and their video recordings were excluded from the analysis.

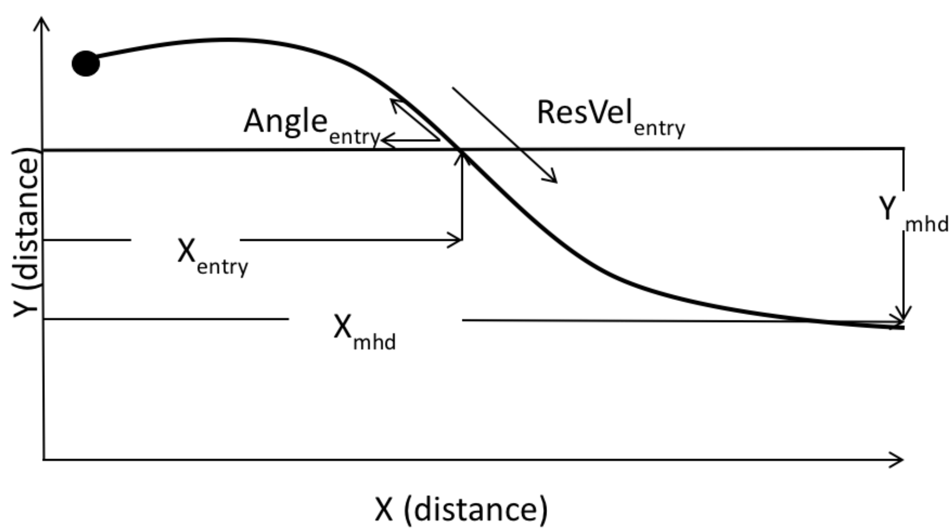

Figure 2 – Dependent variables included head height above water surface during the 'set position' (Y_{set}), distance from the wall at head entry (X_{entry}), resultant velocity at head entry ($ResVel_{entry}$), horizontal velocity at entry ($XVel_{entry}$), maximum depth of the center of the head (Y_{mhd}), head speed at maximum head depth ($ResVel_{mhd}$), distance from the wall at maximum head depth (X_{mhd}), and entry angle ($Angle_{entry}$). Units are either m, $m \cdot s^{-1}$ or degrees.

Statistical Analyses

Normality of the paired data was inspected using histograms and quantile-quantile plots for all variables. Due to deviations away from the normal distribution, the non-parametric Wilcoxon Signed-Rank test was selected to assess differences between the ledge (L) and non-ledge conditions (NL). All tests were conducted as paired one-tailed tests (L > NL) using the exact distribution with statistical significance set at α =.05. The 95% confidence intervals for the mean difference between the ledge and no-ledge conditions were constructed using bias-corrected and accelerated (BCA) bootstrap confidence intervals using 10,000 bootstrap samples.

Results

Participant descriptive characteristics are provided in Table 1, while Table 2 displays the comparison for the parameters measured in each start condition.

Table 1. Descriptive characteristics for 61 subjects

	Mean ± SD	Median
Age (yr)	16.6 ± 1.3	16.4
Height (cm)	173.5 ± 9.3	175.0
Weight (kg)	67.8 ± 10.1	65.3
Years of Experience (yr)	5.0 + 2.4	5.0

Initiation of Start and Entry:

Mean ± SD, range, mean difference with 95% confidence interval, and statistical significance from the one-tailed Wilcoxon Signed-Ranked test for all dependent variables are presented in Table 2. During the initiation of the backstroke start and entry significantly greater values were observed when using the ledge in X_{entry} (mean difference 0.10 m, 95% CI [0.07, 0.14 m], p <.001), $ResVel_{entry}$ (0.36 m·s^{-1}, 95% CI [0.14, 0.56 m·s^{-1}], p <.001), and $Angle_{entry}$ (3.47°, 95% CI [-0.75, 7.20°], p = .030). No differences were observed between the ledge and no-ledge conditions in the Y_{set} position (0.01 m, 95% CI [-0.02, 0.03 m], p = .256) or $XVel_{entry}$ (0.15 m·s^{-1}, 95% CI [-0.04, 0.37 m·s^{-1}], p = .063).

At Maximal Head Depth:

When swimmers reached maximal head depth, significant increases when using the ledge were observed in X_{mhd} (0.08 m, 95% CI [0.00, 0.17 m], p = .008) and Y_{mhd} (0.05 m, 95% CI [0.02, 0.08 m], p <.001). No significant change in $ResVel_{mhd}$ was observed when using the ledge (-0.01 m·s^{-1}, 95% CI [-0.09, 0.08 m·s^{-1}], p = .651). See Figure 3 for scatterplot of this distribution.

Table 2. Comparison between ledge and no-ledge conditions during backstroke starts for 61 subjects

	Ledge		No-Ledge		Mean Paired Difference (95% CI)	*p*-value
	Mean ± SD	Range	Mean ± SD	Range		
During Set Position & Entry						
Y_{Set} (m)	0.50 ± 0.14	0.22 – 0.94	0.49 ± 0.13	0.21 – 0.88	0.01 (-0.02, 0.03)	.256
X_{entry} (m)	1.61 ± 0.59	0.50 – 2.96	1.50 ± 0.53	0.43 – 2.72	0.10 (0.07, 0.14)	<.001
$Angle_{Entry}$ (°)	43.13 ± 16.97	7.37 – 73.16	39.66 ± 18.11	4.45 – 78.87	3.47 (-0.75, 7.20)	.030
$ResVel_{Entry}$ ($m \cdot s^{-1}$)	3.44 ± 0.97	1.58 – 5.30	3.08 ± 1.00	1.00 – 5.37	0.36 (0.14, 0.56)	<.001
$XVel_{entry}$ ($m \cdot s^{-1}$)	2.24 ± 0.88	1.04 – 4.42	2.09 ± 0.92	0.77 – 4.64	0.15 (-0.04, 0.37)	.063
At Maximal Head Depth						
Y_{mhd} (m)	0.54 ± 0.21	0.05 – 1.04	0.49 ± 0.18	0.10 – 0.96	0.05 (0.02, 0.08)	<.001
X_{mhd} (m)	4.18 ± 0.58	2.61 – 5.74	4.09 ± 0.63	2.53 – 6.00	0.08 (0.00, 0.17)	.008
$ResVel_{mhd}$ (m)	1.03 ± 0.35	0.50 – 2.37	1.04 ± 0.34	0.37 – 2.12	-0.01 (-0.09, 0.08)	.651

Values are presented as mean ± standard deviation (SD), range, mean paired difference with 95% confidence interval from BCA bootstrap, and p-value from one-tailed Wilcoxon Signed-Rank test.

Y_{set} = maximal head height at initiation of the backstroke start; X_{entry} = horizontal distance from wall at entry; $Angle_{entry}$ = angle of entry; $ResVel_{entry}$ = resultant head velocity at entry; $XVel_{entry}$ = horizontal velocity of head at entry; Y_{mhd} = vertical depth of head at maximal head depth; X_{mhd}= horizontal distance from the wall at maximal head depth; $ResVel_{mhd}$ = resultant velocity at maximal head depth.

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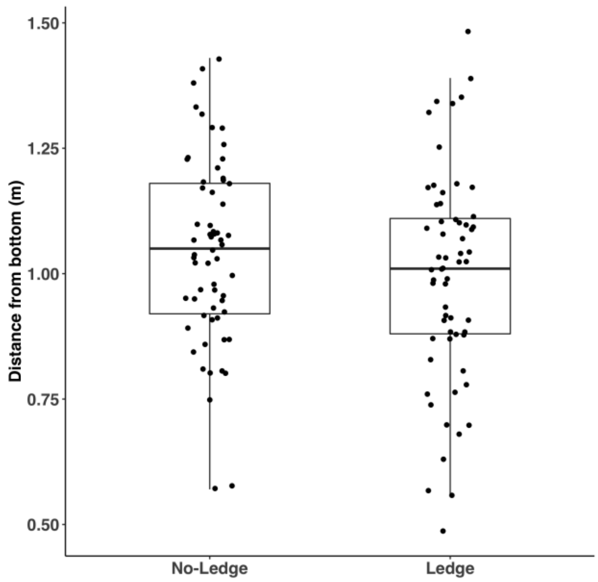

Figure 3 - Distribution of distance between center of the head and the bottom of the pool (m) at maximum head depth in 1.52 m pool depth. Values are statistically different at the $p < .05$, the mean difference reached is 0.05 m (95% CI 0.02, 0.08) m greater 'with ledge'.

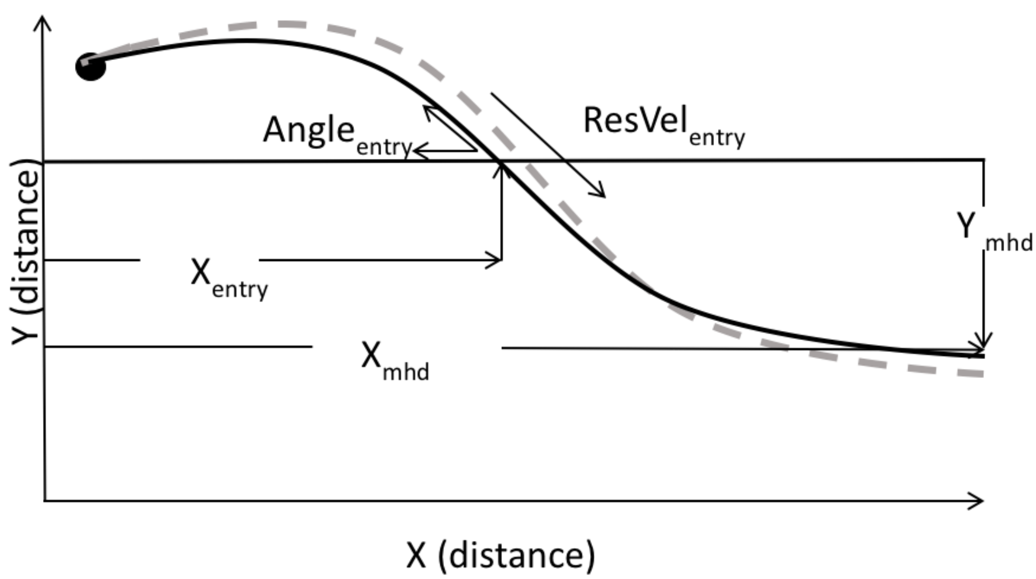

Figure 4 - Differences in the pathway of the center of the head in 'ledge' and 'no ledge' conditions.

Figure 4 shows the pathway of the center of the head and provides a graphic representation of the differences between the two conditions which include a greater entry angle, a deeper maximum head depth, a greater velocity at entry and a greater distance from the wall and at maximum head depth. The grey trajectory line is "with ledge" and the black line is "no ledge."

Discussion

The primary purpose of this study was to assess the safety-related consequences of implementing a commercially available starting 'ledge' during the execution of competitive backstroke starts by adolescent swimmers in a novice setting. Previous literature from our lab characterized variables pertaining to normal backstroke starts (head depth and speed, Cornett et al., 2011). Only a single report analyzing backstroke starts of "high-level swimmers" while using a 'ledge' was found (Barkwell & Dickey, 2017). The lack of information in this regard is an issue as USA Swimming has already approved the ledge for use by all swimmers in competition. In contrast, the organization specifically tasked at overseeing high school competition (NFHS) has completely banned use of the ledge in competition. While the starting ledge has also been approved for use by FINA, the minimum pool depth standard for FINA international competition is 2.0 m as opposed to the minimum 1.2 m water depth standard held by USA Swimming and NFHS. The two issues that are relevant for consideration in this decision are therefore: 1) minimal water depth as an added risk factor, and 2) potential implications of the ledge on velocity and head depth specifically for relatively novice athletes. The present study was directed primarily to provide empirical evidence for both issues as they pertain to the safety concerns in shallow water.

Initiation of Start and Entry

These variables describe the instant just before and during the moments when swimmers first enter the water and begin to affect their trajectory with changes in arm position. Our data reveals that the mean distance at water entry (X_{entry}) was 0.10 m (95% CI 0.07, 0.14 m) further from the wall with use of the ledge. This is consistent with the findings reported in the recent study by Barkwell and Dickey (2017). While we did not measure the actual forces generated by the swimmers during the start and therefore cannot state that this finding is specifically due to the introduction of the ledge, there does not appear to be any alternative explanation. Mean values for the starts performed with the backstroke ledge were 0.36 $m \cdot s^{-1}$ (95% CI 0.14, 0.56 $m \cdot s^{-1}$) faster ($ResVel_{entry}$) and resulted in 3.47° (95% CI -0.70, 7.25°) steeper angle of entry in comparison to starts performed without a ledge (Figure 4). With concern for swimmer safety, one can envision that an increase in speed and/or an increase in entry angle (closer to perpendicular) would put an athlete at greater risk for sustaining injury in shallow water. Whether or not the magnitude of change in these variables would alter the severity of any injury sustained, compared to an injury from a start without the ledge, is less clear. The small but significant increase in velocity at head entry does not cause the mean value to exceed any additional risk threshold and neither does it appear to carry through to maximum head depth (Table 2). As mentioned previously, the time available for swimmers to alter their trajectory upon water entry is minimal and therefore the observed increases in speed and angle at entry with the starting ledge, though small, must be interpreted as representing an increase in risk.

At Maximal 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 m·s^{-1} (sufficient momentum to dislocate the adult cervical spine; Stone, 1981 from Blanksby, Wearne, & Elliot 1996), 1.20 m·s^{-1} (sufficient momentum to crush the cervical spine; Stone, 1981 from Blanksby et al., 1996) , 1.90 m·s^{-1} (15% risk of serious neck and head injury; Viano & Parenteau, 2008), and 3.40 m·s^{-1} (50% risk of serious neck and head injury; Viano & Parenteau, 2008). These later estimates of the threshold velocities were derived primarily from pendulum, linear impact, or inverted drop experiments using cadavers (Viano & Parenteau, 2008). Some were conducted with the cadavers in a supine position while others with the cadavers in the prone position. No mention of differences in injury outcomes were 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). Figure 5 represents the critical thresholds in relation to the witnessed $ResVel_{mhd}$ values in the present study and shows that nearly all (93.44 %) of the backstroke starts filmed resulted in head speeds in excess of that suggested as capable of dislocating the adult cervical spine (> 0.6 m·s^{-1}) and more than a quarter (28.69 %) of starts filmed presented sufficient momentum to crush the cervical spine (> 1.2 m·s^{-1}) if an impact was to occur. It is important to note that none of our values are for vertical velocity, rather the velocity tangent to the trajectory. At maximum head depth, the swimmer is traveling in the horizontal plane prior to any movement back toward the water surface. Head speed at maximum head depth, thus represents a risk of "potential" injury or "worst case" which is dependent upon the swimmer's trajectory.

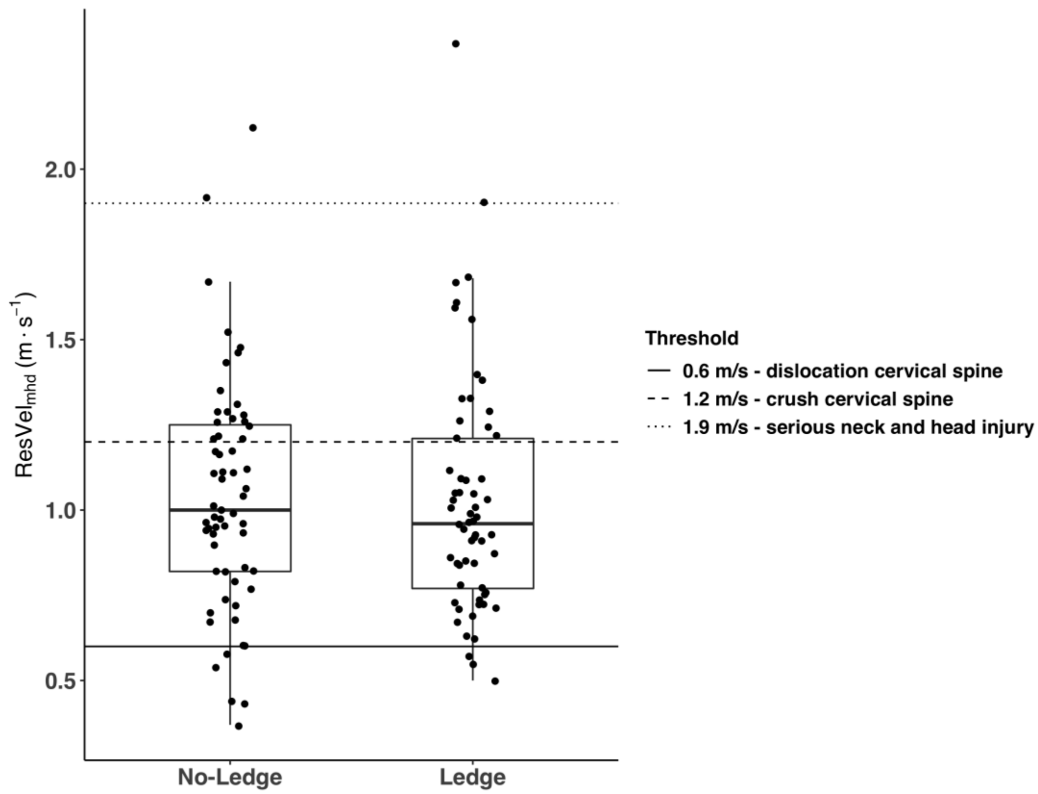

Figure 5 – Resultant velocity of center of the head at maximal head depth (ResVel$_{mhd}$) with proposed thresholds for head and neck trauma.

Three velocity thresholds are depicted by horizontal lines: 0.60 m·s^{-1} (sufficient momentum to dislocate the adult cervical spine; Stone, 1981 from Blanksby, Wearne, & Elliot 1996), 1.20 m·s^{-1} (sufficient momentum to crush the cervical spine; Stone, 1981 from Blanksby et al., 1996) , 1.90 m·s^{-1} (15% risk of serious neck and head injury; Viano & Parenteau, 2008), and 3.40 m·s^{-1} (50% risk of serious neck and head injury; Viano & Parenteau, 2008)

Distance from the wall, depth, and speed at maximum head depth were included as dependent measures in our analysis to remain consistent with previously published research (Cornett et al., 2011). Table 2 displays values for ResVel$_{mhd}$, X$_{mhd}$, and Y$_{mhd}$ observed during backstroke starts with and without the ledge. As mentioned, no difference in speed at max head depth (ResVel$_{mhd}$) was observed between the two conditions. This finding is contradictory to that of increased speed at start entry observed with the ledge, as it would seem an increase in speed at entry would translate to an increase in speed a maximal head depth. Swimmers on average attained maximal head depth (X$_{mhd}$) 0.08 m (0.00, 0.17 m) farther from the wall as well as deeper relative to the water surface when using the ledge. It could be argued they spent “more time” in the water, accounting for the lack of difference in speed despite being both farther and deeper. We speculate, however, that perhaps the loss of the initial velocity reflects the relatively modest skill level of these swimmers. Higher-level swimmers might have resulted in a different outcome at maximum head depth (see Barkwell & Dickey, 2017).

Perhaps the most concerning finding in this study was that swimmers attained a mean maximal head depth at 0.05 m deeper with the starting ledge. As the results pertain to swimmer safety, the lack of an increase in speed at maximal head depth suggests the ledge does not appreciably increase the risk of injury relative to a typical backstroke start should a swimmer collide with the bottom of the pool. Nonetheless, risk of injury during a backstroke start is a two-component problem involving depth and speed. Because the average head depth attained by the swimmers was greater with the ledge, while maintaining speeds capable of injury, the backstroke starting ledge once again, although modest, seemingly increases the potential risk of sustaining an injury.

Additionally, it should also be noted that equipment malfunction of the backstroke starting ledge has recently caused the need for re-swims at numerous high-level competitions (Anderson, 2017; Hart, 2018). The malfunction of the starting ledge caused high-level swimmers to be unable to execute their normal backstroke start and therefore may have increased risk due to equipment failure. This potential for further increase in risk due to ledge malfunction must be coupled with the evidence for increased risk from successful use of the ledge found in this study.

Limitations

While this study provides information on the potential increased risk of injury with a novice swimmer's use of a backstroke starting ledge, the interpretation of the results must be considered within the study's methodological constraints. As the study aim was to investigate novice use of the ledge, the backstroke ledge depth was not standardized for all athletes, nor were they given a familiarization period with the starting ledge. This of course is influential in the outcome of the start (De Jesus et al., 2013). In turn athletes may have altered how they utilized the ledge between trials, increasing the variation in start depths we observed. Additionally, the lack of ledge depth standardization limits the individual applicability of our results. The present study can only speak to the increased risk of injury due to implementation of the backstroke starting ledge at self-selected depths in a novice athlete population. It cannot specifically characterize how different set ledge heights at the start will influence safety risk factors.

Conclusions

Evaluation of backstroke starting ledge safety was necessitated by a petition to the NFHS to allow use of the ledge in high school swimming during competition in the United States. The present study assessed the injury risk difference between backstroke starts with and without a starting ledge, in high school aged athletes with no prior experience using a ledge. Several variables (5 out of 8) associated with an increased risk of incurring injuries during the execution of the current iteration of the competitive backstroke start were shown to change when using the 'ledge'. However, previous research has identified velocity thresholds above which, upon impact, the potential for catastrophic injury is significant. The ledge does not appear to cause any velocity threshold to be exceeded that wasn't already exceeded without the use of the ledge. From the perspective of safety however, swimmers' starts were deeper, at a greater entrance angle, and further from the wall while using the 'ledge'. The differences incurred were modest but none-the-less statistically significant. These data are supported by a recent report by Barkwell and Dickey (2017) and further extend their findings by providing additional data for the underwater portion of the backstroke start with the ledge. Additionally, the increased risk caused by successful use of the ledge cannot be separated from the increased risk that may result from ledge malfunction. We conclude that, just as a competitive race can be won or lost by a hundredth of a second, from the perspective of swimmer safety, the margin of error when executing a racing start is likewise small. Anything that reduces that margin of error may be important in the real world setting particularly when dealing with young, relatively novice athletes. As we are unaware of any catastrophic injuries occurring as a result of wall foot slippage during the execution of a backstroke start, the increased risk that may result from the widespread usage of the backstroke ledge in shallow water should be considered carefully. Given our results, it is difficult to endorse the acceptance and adoption of the ledge for novice cohorts such as those used in this present study.

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