Report: Head Depth and Head Speed During Competitive Backstroke Ledge Starts

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Summary:

Recently, a commercially available starting ‘ledge’ designed to reduce foot slippage during the execution of the backstroke start has been introduced into competitive swimming. For the purpose of identifying potential safety consequences, the present study sought to determine whether or not the head depths, speeds, and distances attained when executing backstroke starts are increased as a function of ledge use. Competitive backstroke starts were performed by high school-aged (n = 66) swimmers in 5 feet (1.52 m) of water during a closed testing period. Swimmers were filmed using a Simi Reality Motion System in calibrated space using three cameras. Dependent measures were maximum 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 ($Res_{vel\ entry}$), 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 condition showed significant median increases in X_{entry} (L 4.61 ft; NL 4.27 ft, p=<.001), $Resvel_{entry}$ (L 10.50 ft*s^{-1}; NL 10.30 ft*s^{-1}, p=0.01), $Angle_{entry}$ (L 43.45°; NL 36.23°, p=0.04), X_{mhd} (L 13.81 ft; NL 13.37 ft, p=0.02), Y_{mhd} (L 1.67 ft; NL 1.62 ft, p=0.01) In conclusion, backstroke starts executed with the ledge affected 5 of 8 dependent measures in the direction associated with increased risk.

Background:

When catastrophic injuries occur in competitive swimming, they are virtually all associated with swimmers coming in contact with the pool bottom following the execution of a racing start (Mueller & Cantu, 2008). The injuries that swimmers incurred upon impact were commonly 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). The head velocity of proficient swimmers commonly reach 13 to 20 ft per second (4-6 m/s) when executing racing starts from a starting block (known as a front dive) into a pool (Cornett et al 2014). And, according to National Federation of State High Schools Association (NFHS) and National Collegiate Athletic Association (NCAA) regulations, pools must minimally be 4 feet (approximately 1.2 m) deep at the starting end (NCAA Rules and Regulations) in order for starting blocks to be used. Given that swimmers are moving around 15 ft per second into a pool depth of 4 ft, if a swimmer initiates a technical error during the execution of the start, there is very little time available (less than 250 milliseconds) for the swimmer to alter their trajectory as a means to avoid a collision with the pool bottom. Anecdotal evidence suggests that swimmers performing a start from the water, as opposed to from a starting block, are less susceptible to a traumatic collision with the bottom of the pool. 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 similar to that of swimmers performing the front dive (Cornet et al. 2011) Furthermore, the backstroke start carries the additional risk of the swimmer being essentially blind to the bottom of the pool, thereby generally eliminating even that small window for trajectory recognition and adjustment.

Because of the flat wall design on many pools and potentially slick touchpad surfaces there exists the possibility for swimmers' feet to slip during the backstroke starts. In order to prevent swimmers from slipping during starts, Omega Timing (and now several others) introduced a temporary ledge (79 cm x 8 cm x 2 cm at base with 10° slope, shown in Figure 1) coated with an anti-slip surface into the commercial market in September 2014. FINA, the international governing body for swimming, and USA Swimming, the United States' governing body for swimming, each approved the ledge for competition shortly thereafter. The NCAA ultimately allowed use starting in the 2015-2016 school year (2015 NCAA men's and women's swimming and diving rules.), and the NFHS has been petitioned to allow the ledges for competition starting in the 2017-2018 school year (https://www.nfhs.org/activities-sports/swimming-diving/). Because the majority of major national and international competitions take place in pools with a minimum depth of at least 6.56 ft (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. That is not true for high school and age group competitions taking place in 4 ft of water. Novice swimmers have been shown to be less predictable and perhaps at great risk in shallow water as compare to experienced elite swimmers (Cornett et al 2012). The important point being there is no current data describing how the 'ledge' affects the trajectories and velocities of backstroke starts. Assessing the risk during usage is thus impossible.

Although marketed as a means to reduce the prevalence of foot slippage, the manufacturers' advertisements and users 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, M, 2016). If the claim of an increased starting angle is, in fact, true, it would likely carry the consequence of increased maximum head depth and head velocity at maximum head depth, thereby increasing the risk of catastrophic collision with the pool floor. However, what is conspicuously absent from the user's manuals from both major manufacturers of the backstroke ledge (Omega Timing and Colorado Time Systems) is the concept of safety insofar as the proper water depth for use of the equipment. There is the possibility that these ledges have no measurable effect on head depth and velocity; however, there is currently a dearth, if not a complete absence, of research on the safety of these backstroke ledges to assert any sort of supportable claim. Therefore, the questions this study intends to investigate are as follows:

Does the ledge alter the swimmer's entrance angle in such a way that it is less acute relative to the water's surface?

Does the ledge result in greater head velocity at maximum head depth?

Does the ledge cause the underwater trajectory (i.e., maximum head depth) to be deeper when compared to racing starts performed without the ledge?

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 a greater velocity at maximum head depth. Both of these changes would be interpreted as representing 'increased risk' especially to the adolescent swimmer in shallow water as the head would be closer to bottom.

Methods:

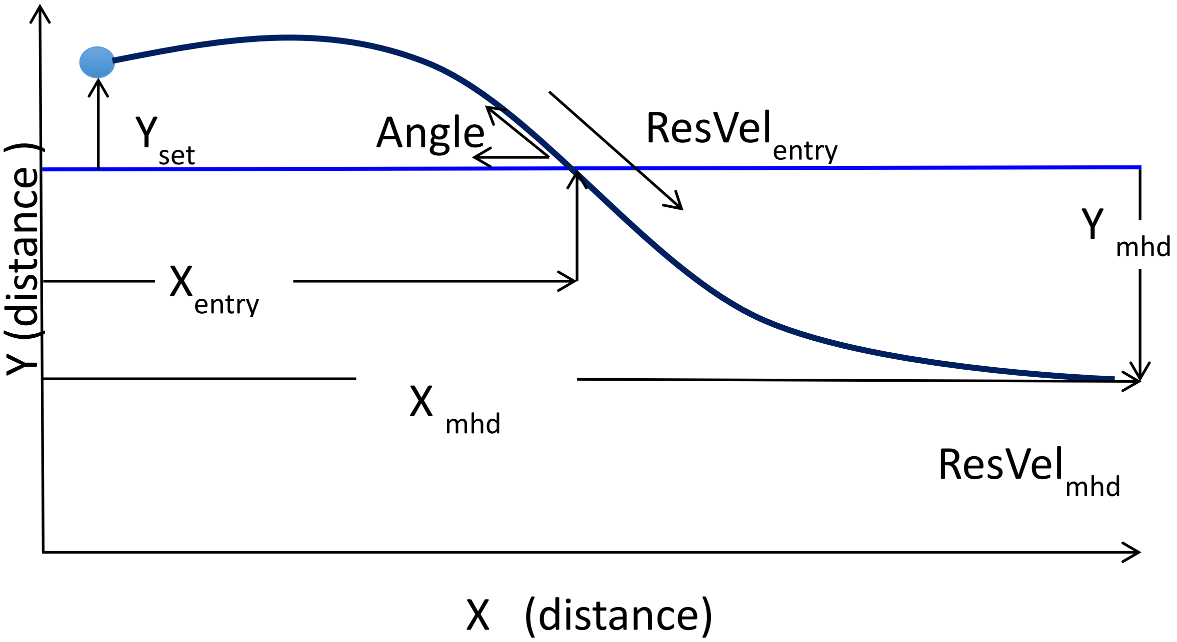
Subjects

Approximately 80 swimmers who were members of their local high school competitive swim team were recruited for the project. Previous literature has not reported discrepancies in start characteristics between sexes (Counsilman, Nomura, Endo, & Counsilman, 1988; Cornett et al., 2010) so no discrimination by sex was made. All swimmers were asked to provide parental or guardian permission before taking part in the research. Prior to initiation the project was reviewed and approved by the University's Committee for the protection of Human Subjects.

Research Design

The swimmers were asked to execute two starts without the backstroke ledge and two starts with the backstroke ledge in 5 feet (1.52 m) of water. The swimmers were allowed to warm up and perform practice starts with and without the ledge prior to the experimental trials. As some of the swimmers' starts did not provide an adequate motor performance for analysis video images from approximately 14 subjects were not analyzed. 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 ($ResVel_{mhd}$), distance from the wall at maximum head depth (X_{mhd}), and entry angle were measured for each trial. The mean of the values for the two starts was used as the respective value for each swimmer.

Figure 1. Dependent variables.



Filming

There was one camera for the “above water space” at the beginning of the start and two cameras for the “water space” through the remainder of the start. The filmed water space was calibrated with a custom-built frame (dimensions 1m x 1m x 3 m) and filmed with two cameras with an overlapping filed of view. The frame was constructed from marine aluminum painted black, with 84 bright yellow foam marker balls (0.05m diameter) as calibration points. The frame was placed 1m from the wall, aligned vertically with the starting block and perpendicular to the side of the pool. The reference points were digitized into a single video frame. A 3D direct linear transformation (DLT) procedure was then used to calibrate the water space into a coordinate system, where the x-axis was positioned horizontally perpendicular to the wall, the y-axis was positioned from the camera-side of the lane to the opposite side of the lane, and the z-axis was positioned vertically parallel to the wall. The ‘in air’ space was calibrated in a similar fashion with the aluminum frame suspended from the surface of the water perpendicular to the starting wall and beginning at the wall and extending three meters towards the center of the pool.

The swimmers resulting images were captured and analyzed using a Simi Reality Motion System that includes hardware and software that were designed specifically for detailed 2D analysis of competitive swimming racing starts. This employs a three-camera system with one camera capturing the above water phase and the other two cameras capturing the below water phase, each one capable of filming up to 120 frames per second at 0.3 megapixels (~640x480 pixels). The underwater cameras were placed within a custom-built housing and placed on top of heavy duty tripods in order to prevent motion from wave force in the pool. The three cameras were synchronized via a synchronization box that allows the simple creation of a continuous video clip for movement tracking above and below the surface of the water. Moreover, the system allows for semiautomatic and manual color-based marker tracking and marker-less object tracking, ultimately leading to expedited and accurate data analysis.

Data Analysis

The dependent measures of interest for this study were maximum head height, distance from wall at entry, entry angle, horizontal velocity at head entry, resultant velocity at entry, maximum depth of the center of the head, resultant velocity at maximum head depth, and distance from the wall at maximum head depth. The starts were stratified according to implementation of the backstroke ledge.

One-way Wilcoxon sign rank tests were conducted to investigate the paired median difference of the effect of the backstroke starting ledge on the dependent variables. We set an alternative hypothesis that the backstroke starting ledge would cause a significant increase on all dependent variables. Statistical significance was set an $\alpha = 0.05$. Symmetrical distribution of the differences of the dependent variables by condition was visually assessed using histogram plots.

Results:

Table 1 displays subject characteristics including: age, height, weight, and years of swimming experience.

Table 2 displays the means and ranges for backstroke starts ‘with’ and ‘without’ implementation of the ledge for maximum 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 ($Res_{vel\ entry}$), 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}).

Table 1. Age is reported in years, Height in feet, weight in pounds, experience in years.

Table 1 Group Mean ± SD, Median, Minimum and Maximum (n=66)

	Mean ± SD	Median	Minimum	Maximum	Range
Age (yr)	16.51 ± 1.35	16.35	14.40	19.20	4.80
Height (ft)	5.68 ± 0.30	5.71	5.05	6.33	1.28
Weight (lbs)	149.75 ± 22.18	145.28	111.99	219.14	107.14
Years of Experience (yr)	5.11 ± 2.33	5	0	12	12

Table 2. Results

Table 2 Mean ± SD, Median, Minimum, and Maximum

	N	Mean ± SD	Median	Minimum	Maximum	Range	p-value
Angle Entry L (°)	58	41.50 ± 17.45	43.45	7.37	73.16	65.79	**0.04***
Angle Entry NL (°)	58	38.19 ± 18.17	36.23	4.45	78.87	74.42	
Res Vel Entry L (ft * s^{-1})	66	11.34 ± 3.09	10.5	5.18	17.39	12.20	**0.01***
Res Vel Entry NL (ft * s^{-1})	66	10.51 ± 3.53	10.3	3.28	17.85	14.57	
Res Vel mhd L (ft * s^{-1})	66	3.28 ± 1.18	3.12	1.38	7.78	6.40	0.73
Res Vel mhd NL (ft * s^{-1})	66	3.33 ± 1.12	3.23	1.21	6.96	5.74	
X entry L (ft)	66	5.40 ± 1.92	4.61	1.64	9.71	8.07	**<.001***
X entry NL (ft)	66	5.08 ± 1.75	4.27	1.41	8.92	7.51	
X mhd L (ft)	65	13.65 ± 1.91	13.81	8.56	18.83	10.27	**0.01***
X mhd NL (ft)	66	13.41 ± 3.03	13.37	8.30	19.69	11.38	
XVel entry L (ft * s^{-1})	66	7.65 ± 2.97	6.96	3.41	14.50	11.09	0.28
XVel entry NL (ft * s^{-1})	66	7.47 ± 3.59	6.53	2.53	17.59	15.06	
Y mhd L (ft)	66	1.75 ± 0.67	1.67	0.16	3.41	3.25	**0.01***
Y mhd NL (ft)	66	1.61 ± 0.58	1.62	0.33	3.15	2.82	
Y set L (ft)	66	1.63 ± 0.43	1.54	0.72	3.08	2.36	0.33
Y set NL (ft)	66	1.62 ± 0.42	1.53	0.69	2.89	2.20	

*Ledge Conidition is significantly greater than No-Ledge $p < 0.05$

Figure 2: Group mean with standard error bars of variables where the ledge is significantly greater than the no ledge condition.

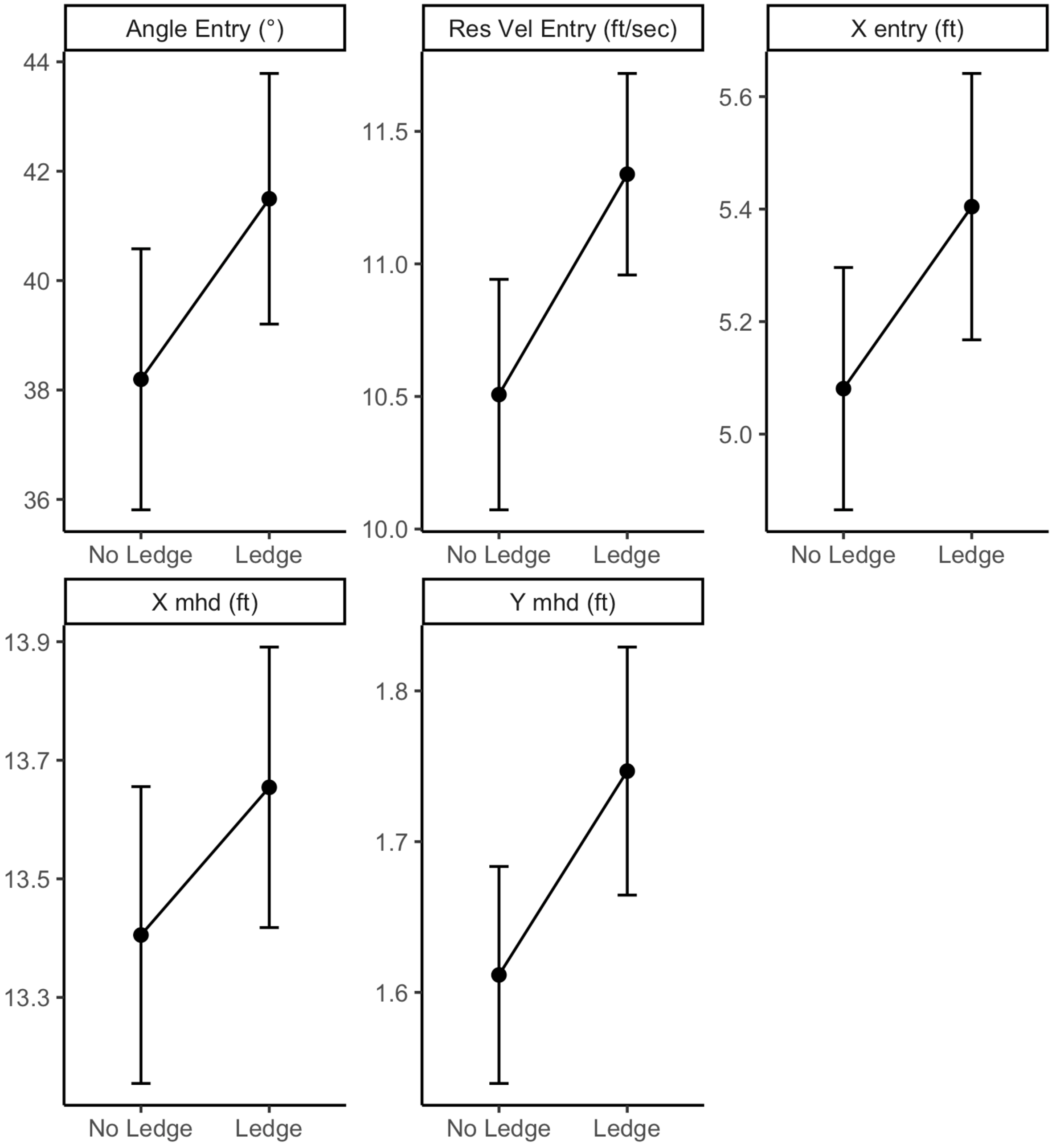


Figure 3: Distribution of distance from the bottom of the pool (inches) at maximum head depth. Though statistically different at the $p<0.05$ level, the difference is about 1.5 inches greater 'with ledge.'

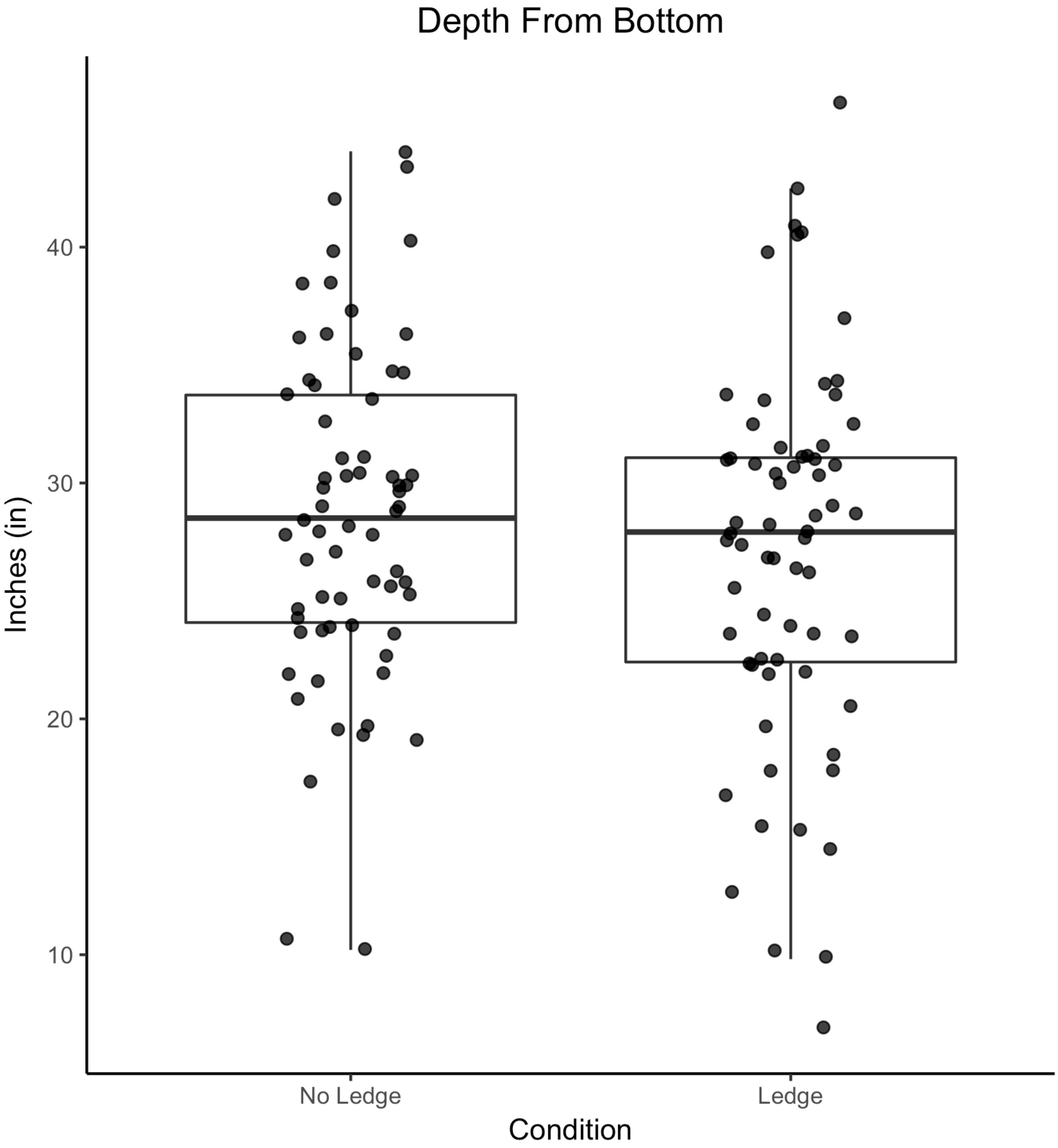
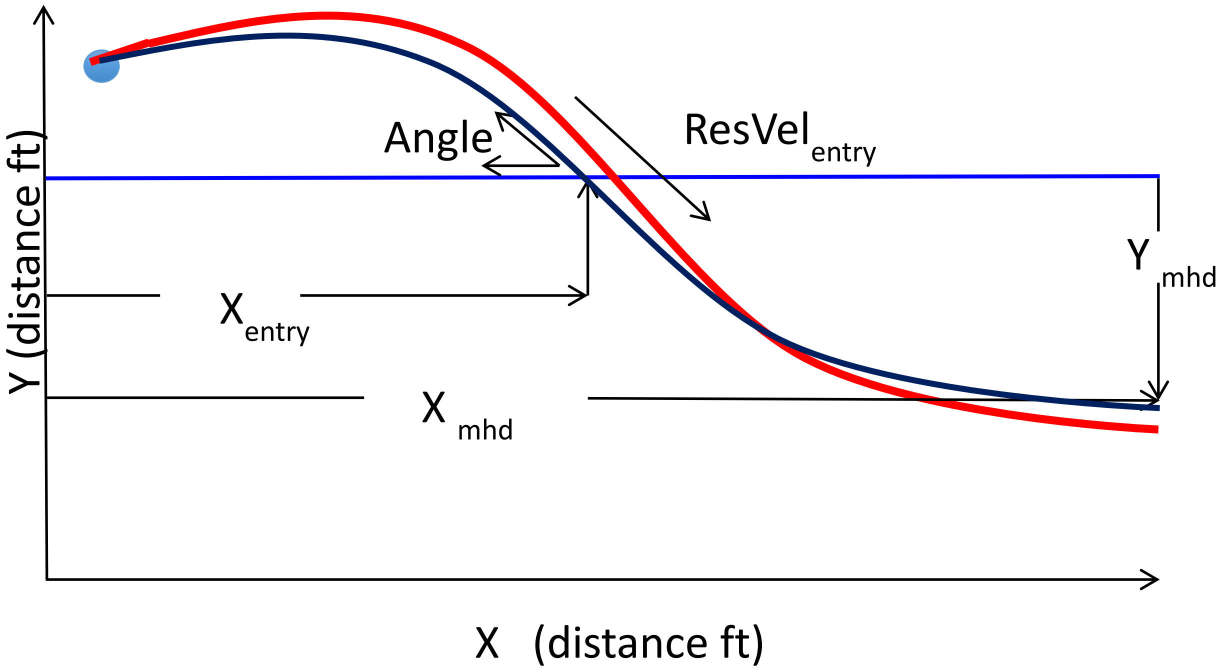


Figure 4. Differences between ‘ledge’ and ‘no ledge’. Graphic representation of the differences between the two conditions include a greater entry angle, a deeper maximum head depth, a greater velocity at entry and a greater distance from the wall and at maximum head depth. The grey (or red when in color) trajectory line is “with ledge” and the black line is “no ledge.”



Initiation of Start and Entry:

At the initiation of the backstroke start there was not a significant increase in the median difference (0.02 ft) of the Y_{set} position under the ledge condition (L = 1.54 ft, NL = 1.53 ft), p = 0.33. However, there was a significant increase (0.30 ft) in the X_{entry} distance L condition (4.61 ft) to NL condition (4.27 ft), p < .001. At entry, the difference in $Xvel_{entry}$ (0.18 $ft*s^{-1}$) was not significantly greater L (6.96 ft) to NL (6.53 ft), p = 0.28. $Resvel_{entry}$ was significantly greater (0.97 $ft*s^{-1}$) L (10.50 $ft*s^{-1}$) to NL (10.30 $ft*s^{-1}$), p=0.01. The $Angle_{entry}$ was statistically greater (3.56°) with L (43.45°) to NL (36.23°), p=0.04.

At Maximal Head Depth:

Interestingly, $Resvel_{mhd}$ was not significantly greater (-0.08 $ft*s-^{1}$), L (3.12 $ft*s^{-1}$) to NL 3.23 ($ft*s^{-1}$), p=0.73. The X_{mhd} significantly greater (0.12 ft), L (13.81 ft) to NL (13.37 ft), p =0.01. Depth at maximal head depth (Y_{mhd}) was significantly increased (0.12 ft) under L (1.67 ft) compared to NL (1.62 ft), p=0.01.

Conclusions:

A number of the 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. However, previous research has identified velocity thresholds above which, upon impact, the potential for catastrophic injury is significant. As an example, it has been suggested that velocities above about 2 ft/sec are consistent with cervical vertebra dislocation. The ledge does not appear to cause any velocity threshold to be exceeded that wasn't already. From the perspective of safety, swimmers' starts were deeper, at great entrance angle, and further from the wall. Admittedly, the differences incurred were modest but none-the-less significant. Just as in a competitive race, one that can be won or lost by a hundredth of a second, the margin of error when executing racing starts is likewise small. Anything that reduces that margin of error may be important in the real world setting particularly when dealing with young novice athletes.

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