# A Biomechanical Analysis into Backstroke Start Kinematics: The Influence of a Backstroke Start Device.

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**Citation** Budzynski-Seymour, E., Steele, J., Langdown, L., & Jessop, D. (2019, January 11). A Biomechanical Analysis into Backstroke Start Kinematics: The Influence of a Backstroke Start Device. https://doi.org/10.31236/osf.io/2vams

## ABSTRACT

**Background:** Backstroke starts have received little scientific attention; this may be due to the ongoing modifications to rules but also the fact that the majority of swim starts occur from a dive. As such, this has been the focus for much swim start research. Backstrokers face the problem of slipping from the wall which is a reasonably common mishap and has serious consequences for the competitor. FINA approved the use of a new backstroke start ledge to help avoid this mishap and therefore the aim of the study was to investigate what advantages come from using this ledge (L) over the wall (W). **Methods:** Twelve well trained male and female competitive swimmers took part in the study and completed six maximum effort sprints; three under each condition. **Results:** The results showed significantly greater flight distance (L = 4.22m±0.42, W = 4.06m±0.35, $p<0.05$) and peak hip height during the flight phase (L = 0.39m±0.15, W = 0.20m±0.14, $p<0.01$) when using the ledge. **Discussion:** It was concluded therefore that the ledge positively effects backstroke start performance during the flight phase of the start.


## INTRODUCTION

### 1.1 Swimming starts

The swimming start is a crucial feature of all swim events; research has found that it can contribute to performance up to 15 m, or 30% of a 50 m race (Theut and Jenson 2006; De Jesus *et al.,* 2010). The start can be defined as the time elapsed since the starting signal to the moment the swimmer reaches the 15 m mark (Jorgic *et al*., 2010). The popularity of swimming has increased and subsequently race analysis has become a regular feature in many international swim meets (Cossor and Masson 2001). This appears to have driven changes in techniques and technologies including the introduction of the back fin to the starting block (Vantorre *et al.,* 2014; Beretic *et al.,* 2012). This led to the development of a new dive start style, the modified track start, where the swimmer places their back foot on the raised fin. Research into the effectiveness of this new fin has shown that it provides a higher horizontal velocity and block horizontal force; which were sustained throughout the time to both 5 m and 7.5 m (Honda *et al.,* 2010). Using the fin, a significant difference ($p$=<0.01) between the two conditions was reported for time to 5 m; 1.62 s with the fin and 1.66 s without. This demonstrates the extent to which new technologies can improve start performance.

### 1.2 Backstroke starts

The backstroke start is the only swimming start that is initiated whilst submerged in the water, this renders analysis of technique difficult and may explain the lack of scientific research currently available. Furthermore, rule changes and starting block modifications have led to research quickly becoming out of date (De Jesus *et al*., 2014). For example, in 2014 FINA approved the use of the new starting device resulting in all previous research based on using the wall becoming redundant.

For the backstroke start, the swimmer starts in the water facing away from the direction of travel. He or she holds vertical or horizontal handgrips with their feet in contact with the wall (Maglishco 2003). After the starting signal, the swimmer pushes off from the wall and enters the water, a hole entry technique being preferred (Takeda *et al.,* 2014). The hole entry is a technique whereby the swimmer enters the water through a small entry point, adopting a position so that their whole body enters through this area. From here to the end of the start, the swimmer needs to minimize hydrodynamic drag to maintain their movement through the water to the breakout and swim (Novais et al., 2012). During the underwater phase, the swimmers use dolphin kicks completed on their backs. The backstroke start can be broken down into distinct phases: the block phase, take off, the flight phase, and finally the underwater phase. Figure 1 below illustrates the different phases.

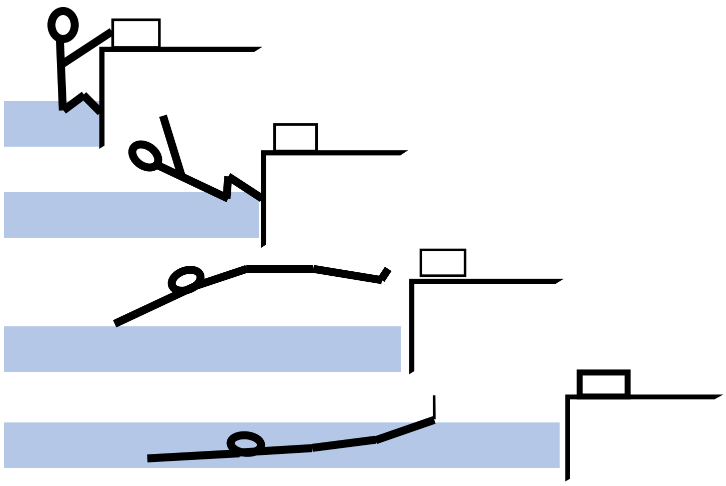

Figure 1: Phases of a backstroke start

1.3 Block and take off phases

The block phase is a crucial part of the start, and during this phase two distinct actions must be optimized: a rapid reaction to the starting signal and the generation of a high impulse (Vantorre *et al.,* 2014). Track sprinting research has shown that there needs to be a compromise between spending increased time on the blocks to create a high velocity on takeoff, and limiting contact time leading to reduced external power output. Consequently, spending too long on the block is not a characteristic of a successful start (Bezodis *et al.,* 2010; Vantorre *et al*., 2014). For swimming a high velocity at takeoff is especially important as the levels of velocity achieved here are the greatest achieved at any point in the whole race. It is therefore crucial to attempt to maintain this throughout the following phases (Honda *et al*., 2010).

1.4 Flight and entry phase

The aim of this phase is to jump as far as possible to cover the furthest distance at the highest velocity. To maintain their speed, swimmers adopt a streamlined position and enter the water using the 'hole entry technique'. By doing this the swimmer minimizes the levels of drag they experience in the water (Takeda *et al*., 2015). The hole entry technique involves all the swimmer's body parts entering the water through the same point; hands first, followed by the head, trunk and finally legs; this creates less drag and allows for a fast entry and subsequent underwater phase (Takeda *et al.,* 2015).

1.5 Underwater phase

This phase is defined as the moment from when the swimmer's head enters the water to when they resurface and start their swim phase (Thor *et al*., 2015). There are two factors that affect the efficiency of this phase; hydrodynamic drag and initial push off velocity (Novais *et al*., 2012). This means that it is important to have an effective transition from air to water where the streamlined position of the swimmer is maintained and they reach the optimal depth under the water; this will allow for the velocity developed at the previous stages to be maintained (Vantorre *et al.,* 2014; Ellipot *et al.,* 2010). Depths that have been found to be most beneficial for lower levels of drag are between 0.5-0.7m below the surface of the water (Thor *et al* 2015; Novais 2012).

1.6 The problem and solution

Traditionally, a backstroke swimmer must balance horizontal and vertical push off forces to gain large horizontal velocity whilst also minimizing hydrodynamic drag, the added complication for backstroke swimmers is achieving this on a vertical surface that is often wet and provides little grip to aid the movement. If the vertical component is too small, the athlete will remain too low in the water and not achieve the 'hole' entry however, too large a vertical component may increase the likelihood that the athlete might slip during push off. De Jesus *et al.* (2014) noted that such a slip is a reasonably common mishap and has disastrous results for the competitor. In 2013 the International Swimming Federation (FINA) legalized the use of an angled fin on the starting block for the athlete to push-off from. De Jesus *et al.* (2014) state that this will reduce the risk of slipping due to minimizing the requirement for friction in order to produce vertical force. Recent research into the ledge has found that it increases the vertical centre of mass displacement, take-off angle and flight distance (De Jesus *et al.,* 2014).
Furthermore, by using the ledge the wall-feet contact is improved allowing the swimming to focus on their take off rather than maintaining a stable position (De Jesus *et al.,* 2016). More research is needed to ascertain where the specific advantages on using the ledge when compared to using the wall.

1.7 The Aim

The aim of this study was to investigate any advantages of using the Colorado Time Systems backstroke start device in backstroke swimmers. Due to the suggested benefits to feet-wall contact and improvements in the take offer and considering the limited research that exists favoring the use of backstroke ledges; it was hypothesized that the new backstroke ledge would positively affect the flight of the swimmers compared to using the wall.

## MATERIALS & METHODS

*Participants*

Twelve well-trained competitive club level swimmers volunteered to take part, 7 males (mean age 41.4 ± 17; mean training years 25 ± 19.9) and 5 females (mean age 33.4 ± 10; mean training years 21.4 ± 12.7). The participants were recruited using convenience sampling. All participants were healthy (no serious injury or illness in the last 6 months) and they engaged regularly in swimming training, attending a minimum of three sessions per week and regular competitions. They all wore standard swimsuits. Each participant competed both a physical activity readiness questionnaire (PAR-Q) and informed consent prior to the testing; and the Southampton Solent Ethics Committee approved the protocol (ID No. 370).

*Protocol*

Prior to the data collection all participants spent time on the day familiarizing themselves with the new backstroke starting ledge. Upon arrival, the participants were instructed to complete their normal pre-race warm up. A cross over study design was utilized so each participant completed six maximum effort backstroke starts, three using the wall and three using the ledge, with the order randomized. Participants were instructed to sprint past 15 m, and could choose whether to use the vertical or horizontal handgrips; however, they had to be consistent in their choice to allow for comparison between starts. Previous research has reported that different handgrips do not affect start kinematics (De Jesus *et al.,* 2015). Between each sprint an active rest period was given to allow for recovery. The sprints abided by the FINA rules (FINA 2014), and for the starts a simultaneous light and auditory signal was provided.

The testing was completed at a 6 lane 25 m indoor pool. The starts were filmed in the sagittal plane using a digital video camera (Canon HV20E, Canon Inc. Japan) placed on a tripod (475 Geared Tripod, Manfrotto, UK) 5 m away from the swimmer on the poolside. The camera operated at a 50 Hz frequency and a shutter speed of 1/250 s. To aid with post testing analysis a calibration object and trial number were placed in the view of the camera. To initiate all starts a Swiss Timings start device (StartTime IV acoustic start, Swiss Timings, Corgémont, Switzerland) was used. This was placed on the opposite side of the pool, allowing it to be in view of the camera and to be heard by the swimmers.

*Kinematic Analysis*

**Table 1: Variables analysed**

| **Variable:** | **Description:** |
|---|---|
| Total Flight Time | Time elapsed from the hands leaving block to hands entering the water. |
| Total Flight Distance | Distance between the wall and the point of hand entry. |
| Average flight Horizontal Velocity | Average horizontal velocity of the flight phase – between the wall and hand entry. |
| Average Flight Acceleration | Average acceleration of the flight phase – between the wall and hand entry. |
| Peak Vertex height | Highest point of the vertex during the flight phase. |
| Back Arch Angle and entry | Arch angle of the back at the point of entry, calculated using the shoulders, mid-point of back, and hips. |
| Peak Hip Height | Highest point of the hip during the flight phase. |

All six trials for each participant were manually digitized in ProAnalyst 3D (3D Professional Edition, XcitexUSA) which uses sub-pixel cursor, and the data exported into Microsoft Excel. This provided all the results for the variables which can be seen in Table 1 below.

*Statistical Analysis*

Data was analyzed using the Statistical Package for Social Science (version 22.0; IBM, Portsmouth, Hampshire, UK), significance was accepted at the level of $p<.05$. A Shapiro Wilk test was run to assess for normality (Razali and Wah 2011) and a Bonferroni adjustment to help reduce the likelihood of a type I error. To allow for comparison between the data sets a paired samples *t*-test was used (Price, 2013). Effect size (Cohens *d*) were also calculated with large effects size taken as above 0.80, moderate between 0.50-0.80. and low between 0.2-0.5.

A questionnaire was also administered to a sample of the participants to ascertain their opinion post testing on the effectiveness of the ledge. Those chosen were the more experienced backstrokes as they had more experience with the tradition backstroke starts and be able to notice how the ledge was effecting their performance. The participants were asked to score the following statements on a 5 point Likert scale from strongly disagree to strongly agree:

- The new starting ledge positively affected my backstroke start performance
- The new starting ledge was more effective than using the wall
- I felt confident that I would not slip on the wall during my start using the new starting ledge
- Using the backstroke start ledge would benefit my overall backstroke performance

The Likert scale was chosen to gain an understanding of the psychological effect of the device for the swimmers as a new technology; and this is a common approach to collecting and ranking data (Alan and Seaman 2006) and was analyzed by calculating mean scores from the sample.

**RESULTS**

Flight time (FT), flight distance (FD), average flight horizontal velocity (HFV), and flight acceleration (FA) were calculated for all 12 participants for all three trials both using the ledge and the wall, these are defined in table 1. However, for peak hip height (PHH) only 6 participants were included and for Back Arch Angle at entry (BAA) only 4 were reported as for this to be calculated the hip must have remained out of the water for the flight phase. This was due to the range of abilities in the sample.

The results (shown in Table 2) show significant improvements when using the ledge for both FD ($t(35) = 0.21$m, $p<0.05$) and PHH ($t(13) = 0.19$m, $p<0.05$). Other improvements were also seen including a quicker FT, higher PVH, greater FV, and more efficient BAA; however, these were not statistically significant. In terms of the magnitude of the observed effect: a large effect size was found for both PHH (1.32) and BAA (1.35), FD was 0.51 showing a moderate effect.

**Table 2: Mean and SD and Paired t test results (*P*<.05)**

| Variable | N | Ledge | Wall | *P* value | Effect Size (Cohens *d)* |
|---|---|---|---|---|---|
| Flight Time (s) | 12 | 0.43 ± 0.06 | 0.43 ± 0.05 | 0.11 | 0.25 |
| Flight Distance (m) | 12 | 4.25 ± 0.35 | 4.04 ± 0.26 | 0.03* | 0.51 |
| Peak Hip Height (m) | 6 | 0.39 ± 0.15 | 0.20 ± 0.14 | 0.008** | 1.32 |
| Peak Vertex Height (m) | 12 | 0.99 ± 0.41 | 0.91 ± 0.23 | 0.32 | -0.33 |
| Average Horizontal Flight Velocity (m/s) | 12 | 9.92 ± 0.9 | 9.23 ± 1.5 | 0.72 | 0.08 |
| Flight Acceleration (m/s) | 12 | 22.98 ± 5.45 | 23.44 ± 4.74 | 0.76 | -0.06 |
| Back Arch Angle at Entry (°) | 4 | 177.15 ± 14.40 | 181.95 ± 14.79 | 0.09 | 1.35 |

Table 3 below shows the mean scores from the 5 point Likert scale that was administered to a sample of the participants ($n = 6$). The results show that for all the answers the participants felt the ledge was a positive addition with the highest score coming from their view of how the ledge positively affected their backstroke start performance.

**Likert Scale average score**

| Question | Average |
|---|---|
| The new starting ledge positively affected my backstroke start performance | 4.2 |
| The new starting ledge was more effective than using the wall | 4.0 |
| I felt confident that I would not slip on the wall during my start using the new starting ledge | 3.7 |
| Using the backstroke start ledge would benefit my overall backstroke performance | 3.8 |

## DISCUSSION

The aim of the study was to analyze the effect of the new backstroke starting device on backstroke start performance. Swimming performance is measured by the summation of the start time, swim time, turn time, and finish time; thus, for the best performances swimmers need to master all components (Theut and Jenson 2006). This study focused on the start phase; the results showed that the backstroke starts using the new device led to a better flight distance. The results showed significant improvements from using the backstroke start device for FD and PHH. An improvement in FD enables the swimmer to travel further through the air thus postponing their contact with the hydrodynamic drag met in the water, and a greater PHH will allow the swimmer to adopt a more efficient body position throughout the flight phase leader to an improved entry.

It is important that the swimmer covers a large distance in the air as this reduces the effect of hydrodynamic drag experienced during the start. This study found significant improvements in the flight distance when using the ledge (L = 4.25m±0.35, W = 4.04m±0.26) therefore leading to the conclusion that the ledge start can assist in the reduction of hydrodynamic drag experienced by the swimmers. This was also the case in a similar study by De Jesus *et al*., (2015) who found that the swimmers' flight phase duration increased yet their 5 m time was quicker suggesting a superior flight phase contributes to overall greater performance. This shows the superiority of the ledge in improving the flight phase of the backstroke start.

Another important result found in this study is that regardless of similarities in flight times the distances were greater which implies a greater HFV. Although HFV was recorded and not found to be significant, as its calculation involves both time and distance the lack of significance here could be as a result of type II statistical error from low sample size or trial numbers. Flight velocity is a key characteristic of a successful swim start; and is a consistent theme throughout the literature (De Jesus *et al.,* 2015; De Jesus *et al.,* 2013; Honda *et al.,* 2010; Cossor and Masson 2001; De Jesus *et al.,* 2010). The improvement in the velocity indicated in the current study therefore agrees with the previous findings; where swimmers using a kick start plate found many improvements including a quicker 7.5 m time and higher levels of take-off horizontal velocity. The superiority shown by these variables led to the authors concluding that the kick start lead to improvements in the dive starts of swimmers (Honda *et al.,* 2010). This can also be the case in the current study; a suggested improvement in the horizontal velocity of the swimmers using the ledge allows for a superior backstroke start to be performed.

During the flight phase, swimmers need to modify their body position to ensure they adopt the most efficient entry position. Coordinating the proper lower limb positioning during the take-off phase leads to superior take of angles, with less resistance in the subsequent entry phase; improving the overall backstroke start performance (De Jesus *et al.,* 2015). Arched back posture during the flight phase is important as it helps the swimmer to improve their water reach (De Jesus *et al.,* 2014). Takeda *et al*. (2014) aimed to clarify the factors needed to execute the hole entry technique, the most efficient entry method. Takeda *et al*. (2014) compared backstroke specialists and non-specialists and concluded that the specialists showed early extension speed at the hip joint and that this was an important factor in the hole entry technique. This meant that the swimmers reached the optimal hip angle early on during their flight phase. In addition, it was also noted that hip height was a crucial variable, with an increase in hip height leading to a superior start. In the current study the hip height when using the ledge was significantly greater then when using the wall (L = 0.39 m ± 0.15, W = 0.20 m ± 0.14). This suggests that using the ledge would potentially allow the swimmer to adopt a more effective body position during the flight phase to help achieve the hole entry technique; which will then have a subsequent positive impact on the rest of the start due to the effect that the preceding actions have on the underwater phase (De Jesus *et al.,* 2015). However, it should be noted that this was only the case for those participants ($n$ = 6) for whom we were able to calculate PHH suggesting that the ledge may offer greater benefit for those with more successful backstroke start technique.

The importance of adopting the hole entry technique as stated above is crucial for a low water resistance entry, but it also plays an important role in the subsequent phase, the underwater phase (De Jesus *et al.,* 2015; Naemi *et al*., 2009). The underwater phase of the start was not something specifically analysed in this study, however its importance cannot be ignored. The underwater phase accounts for around 84% of overall start time and it is strongly influenced by both the flight and entry phase (De Jesus *et al.,* 2015). The depth that the swimmer travels during this stage has been researched into and it is recommended that swimmers travels at around 0.5-0.75 m below the surface to meet the minimal amounts of drag; as the amount of drag decreases with depth up to this point (Thor *et al.,* 2015: Novais *et al.,* 2012). As the swimmer's position during this phase is effected by their position in the previous flight and entry phase, it is important therefore that these phases are completed successfully to allow the swimmer to adopt the best position during the underwater phase; resulting in benefits to all components of the start. This study has shown that the ledge brings benefits to the flight phase and therefore may suggest improvements to the underwater phase; however, this is an area for further research to explore.

As stated in the introduction slipping from the wall is a reasonably common mishap; therefore, it is something that is on the mind of a backstroke swimmer when preparing to race (Maglischo 2003; De Jesus *et al.,* 2014). Many swimmers, including Olympic backstroker's have reported the problem of slipping and state that it is something that is part of the backstroker's psyche (Peirsol in FINA 2014). Due to this psychological aspect, the swimmers were asked post testing to fill in a 5 point Likert scale questionnaire to see how they felt the device affected the performance (*n* = 6). When asked 'how much do you agree that the backstroke ledge positively affected your backstroke start performance' the average reply was 4.2; between agree and strongly agree. When asked specifically about overcoming the issue of slipping the response was slightly lower at 3.7, however this was between neutral and agree. The sample nevertheless did seem to agree that the ledge was more effective than the wall as the average score here was 4.0. These results show that after one session with the ledge the swimmers felt there was some benefit to an aspect of their performance; these benefits may be greater after further experience with the ledge. Therefore, not only does the ledge positively affect biomechanical aspects of the backstroke start, the results also show an improvement in the swimmer's psychological view of the start. If in future the issue of slipping is prevented through the use of the ledge, then a cause of anxiety for the backstroke swimmers will be evaded.

4.1 Limitations of the study

Despite the originality of the data, and important additions it provides to backstroke start research, there are some limitations to the study. As noted, the sample size was limited, thus the chance of a type II statistical error may have been increased for a number of variables. It would also have been helpful to aid with post testing analysis to have anatomical landmarks placed on the swimmers. Although this would have helped with the digitization due to the nature of the sport the participants did not have any excess clothing on that disrupted the view of the landmarks aiding in their location. Further, we were limited in access to camera equipment that was able to record high resolution underwater video. Considering the backstroke start begins with the swimmer partly submerged in the water it would have been useful to have been able to examine the effects of the platform upon kinematics of the submersed body segments. This is certainly an avenue for future research. It is worth noting that previous studies investigating swimming starts have adopted a similar camera set up, capturing the flight phase of the starts from cameras placed on poolside (Galbraith *et al.,* 2008).

4.2 Future directions

Future studies should focus on the effects that the ledge has on the underwater phase of the start, and also re-examine the flight phase with a focus on the take-off angles of the swimmers as this is an area where it seems the ledge provides benefits. It is also important that any further studies should allow time for familiarisation with the new ledge to allow the participants to become fully accustomed to the new device.

## CONCLUSION

In conclusion this research has shown that there are benefits to using the new backstroke start device for backstroke starts and it has provided a crucial addition to the limited data relating to the new backstroke start device, and how it can aid backstroke start performance. The results have shown that when compared to a traditional wall start, flight distance and peak hip height are improved. Given that no increase was seen in flight time, the use of a starting ledge can be said increase overall efficiency of backstroke start performance.

## ACKNOWLEDGEMENTS

We would like to thank the swimmers at Basingstoke Bluefins Swimming Club who took part in the study.

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