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REVIEW ARTICLE

The Effect of Waves on the Performance of Five Different Swimming Strokes

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Abstract:

Objective:

Little is known about the transfer of swimming skills from flat, calm conditions to outdoor, unsteady conditions. The aim of the present study was to investigate the velocity decrement of several life-saving, self-rescue and rescue related strokes when introducing waves of different heights.

Methods:

Thirty-three subjects swam twelve 25m sprints each, in a randomized order, in a 3x4 (wave height x stroke) design. The wave heights were flat, medium (ca 20 cm) or large (ca 40 cm), in a specially designed wave-simulating pool. The strokes studied were front crawl, head-up crawl, back crawl and breaststroke. A subgroup swam front crawl, head-up crawl and head-up crawl with fins. A repeated measures ANOVA showed a significant effect of stroke, $F(3,23)=108$ ($p<0.001$), showing that these four strokes have different levels of performance; and wave height $F(2,24)=87$ ($p<0.001$), showing that introducing waves reduced velocity, but there was no interaction effect. The fastest stroke in flat water was not surprisingly, front crawl, followed by head-up crawl, back crawl and breaststroke. When introducing medium or large waves, the order of strokes from fastest to slowest was identical to flat-water conditions. The average velocity decrement when introducing medium and large waves was 3% and 7% respectively. For the subgroup swimming with fins, this was the fastest stroke, followed by front crawl, and head-up crawl. This order did not change when introducing waves, and the velocity decrement was 4 and 2% for medium and large waves respectively (not significantly different from other strokes).

Result:

The conclusion is that the rank order of strokes does not change when introducing waves and that no stroke seems to perform relatively better in unsteady water compared to flat water. Other aspects than performance and velocity should be considered when choosing strokes for swimming in waves, these are discussed in the paper.

Keywords: Swimming skills, Breaststroke, Front crawl, Back crawl, Simulated open water, Unsteady conditions.

1. INTRODUCTION

Drowning accidents happen in many arenas. For instance, in the tropical islands of Hawaii, 41% of drowning accidents happened in a pool setting and 39% in a surf or bay area setting [1]. In Norway only 7% of the drowning cases were in the category "Bathing" – including pool and beach activities, the rest of the accidents in the period of 1998-2010 happened in an outdoor setting (sea, lake, river), *i.e.* over 93% happened in open water [2]. There are only a

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few studies that have investigated swimming performance in outdoor conditions.

The differences in lifeguard performance when swimming in a pool versus swimming in the sea in calm and surf conditions were investigated by Tipton *et al.* [3]. They found significantly slower swimming speed in surf compared to calm sea and in calm sea compared to pool swimming. They found a reduction in swimming performance from a pool setting to calm sea swimming of 10-12%, and from calm sea to surf sea swimming of 30-57%. They also found a significant effect of experience, *i.e.* the less experienced lifeguards suffered the greatest decrement. Furthermore, one study shows an 8% reduction in performance for children performing a 200m swim in waves compared to flat water [4]. The four competitive strokes have been shown to produce a different wake, or make waves of different intensity [5]. The order from lowest to highest wave intensity at identical submaximal speeds was backstroke, front crawl, breaststroke and butterfly. This might lead to a hypothesis stating that the strokes perform differently in waves, but there are no empirical studies that connect wake waves of swimmers to performance in external waves. Little is known about which swimming stroke is the better to use in a surf or wave setting, either as means of self-rescue or when rescuing others.

In competitive swimming, average speed is the performance criterion, economy and drag are major performance determining factors [6] and competitive rules put constraints on the movement solution. In lifesaving the situation is different. Time or speed is not equal to the performance (a saved life is), and the constraints are more related to the situation and weather conditions. In lifesaving various strokes are thus used for several other purposes. Here speed and economy of energy also must play a role, but depending on the situation, tackling unsteady sea, currents, wind, lower water temperature, having visual contact with a victim, obstacles or land, and direct contact towing can determine the outcome. To manage self-rescue and rescue of others, a multitude of strokes can be used, not only front crawl, breaststroke, back crawl (or possibly even butterfly), which are the four competitive strokes, but also combinations of these, head-up strokes, side strokes and the use of fins, to mention a few. However, no empirical data seems to exist on the effectiveness of these strokes in an unsteady water setting.

The four competitive strokes have a clear order of speed and economy. Already in 1974 freestyle was found to be more economical compared to breaststroke [7]. Kolmogorov and Duplisheva [8] examined maximal speed and drag in the four competitive strokes in elite swimmers and found front crawl to be the fastest (v= 1.61 and 1.77 $m \cdot s^{-1}$ for females and males respectively), with butterfly (7% and 6% slower than front crawl for females and males respectively), backstroke (14% and 12%) followed by breaststroke (21% and 23% slower). Similar values for active drag were for butterfly with 3% and 16% more drag than crawl, backstroke had 15% and 7% more drag than crawl and breaststroke had 28% and 7% more drag for females and males respectively [8]. Clearly front crawl is the fastest stroke and also the most economical but is it suited for all conditions? Furthermore, when introducing waves, no information seems to exist about the velocity decrement to be expected nor which stroke might suffer the least decrement in waves, relative to flat conditions.

The purpose of this study was to investigate the velocity decrements of several life-saving, self-rescue and rescue related strokes when introducing waves of different heights, and to discuss traits of the different swimming strokes relevant for the choice of stroke in lifesaving.

2. METHODS

This study is part of a larger project called “Can You Swim in Waves?” It is part of a series of studies in the “Can You Swim” project [9]. The design was a randomized controlled experiment with a 3x4 (wave height x strokes) factor repeated measures, where the subjects were their own controls. Thirty-three (33) subjects of group A (aged 15.6±2.9 years) with 15 girls (height 1.66±.04m and weight 54.1± 5.3kg) and 18 boys (height 1.79±.08m and weight 69.0± 11.2kg) who volunteered for the study and gave their written consent for participation. A second group, group B, consisted of 4 girls and 8 boys, mean age of 16.2±4.0. Those below the age of 18 also provided written parental consent. The subjects´ swimming experience ranged from approximately 4 to 11 years (values estimated). The subjects did not have any extensive experience with open water swimming prior to the study, except for some recreational swimming during the summer- and holiday time. The local ethics committee approved the study, and the guidelines of the Helsinki declaration were followed.

All tests were done in an indoor 25m pool with a water temperature of 27°C. The pool was equipped with a wave-making device called a wave ball (WoW Company, Nanine, Belgium). The ball, which floats on the surface has an internal mechanism of moving weights, constructed such that internal movement results in vertical movement of the ball on the surface (Fig. **1**). The waves are dispersed from the ball in a circular pattern, and reflecting panels along the pool edges make the waves refract back into the pool. The result is an unsteady water surface, behaving chaotically, and with 3 possible levels of amplitude: flat water, small waves (from top to bottom) of 20-40 cm and large of 40-60 cm. All tests were done in a randomized and balanced order such that the potential effect of learning and fatigue was minimized, both for the stroke factor and the wave-height factor.

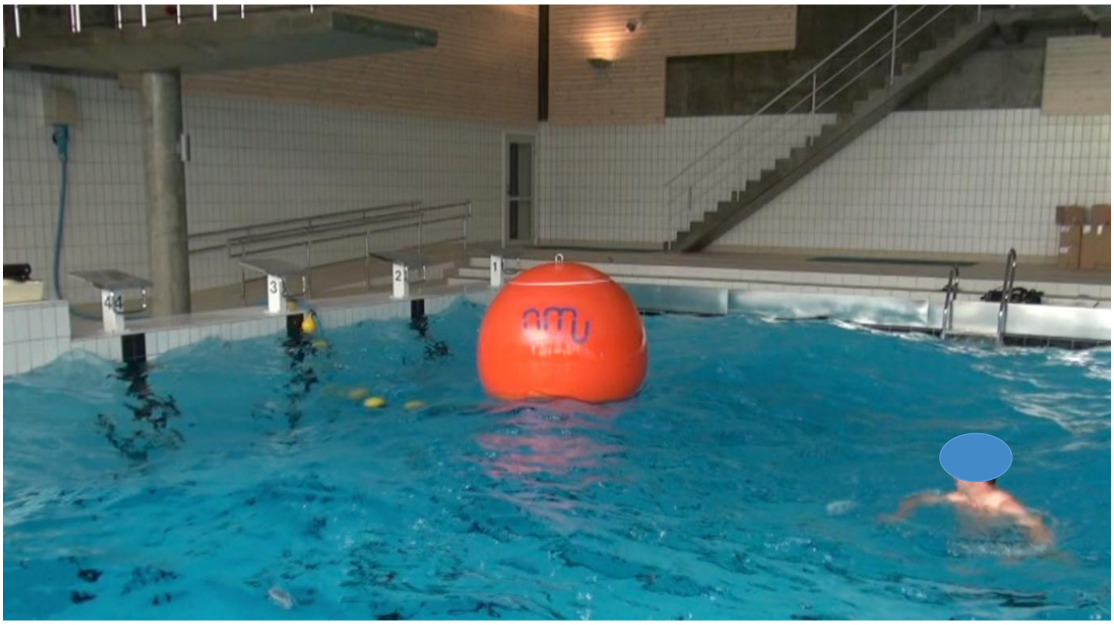

Fig. (1). Setup of wave-making ball.

2.1. Protocol

The protocol consisted of twelve 25m maximal time trial swims, with a resting interval of 3 minutes. This was chosen to avoid inter-trial fatigue, and hence only the intra-trial fatigue would affect the results. The push-off was standardised with a minimal underwater phase (no underwater kicking or stroking after push-off). Each subject swam 4 different strokes in 3 wave conditions (flat, small and large waves). All subjects swam front crawl (head down), head-up front crawl and backstroke. For the fourth stroke, group A swam breaststroke, and group B performed head-up front crawl with fins. All 25m time-trials were timed using a stopwatch operated by experienced swimming coaches, and the stroke count was registered. The timekeeping was randomized in such a way that all timekeepers rotated with respect to which swimmer or conditions that were timed. The coaches were all extensively experienced in timekeeping, and according to [10] this is a reliable method for measuring speed in the present duration domain. Furthermore, a Chronbachs alpha test was run on the data, for all 12 cases (3 wave heights x 4 strokes), for 3 waveheights, and for 4 strokes, yielding alpha values of 0.98, 0.94 and 0.94 respectively. This indicate that our measurements are reliable.

Velocity (v ($m \bullet s^{-1}$)) was calculated as v= [swimming distance] / [time]. Stroke rate (SR ($strokes \bullet min^{-1}$)) was calculated as SR = 60• [stroke count] / [time (s)], stroke length (SL (m)) was calculated as SL = [swimming distance] / [stroke count] and stroke index (SI) as SI=v•SL. The swimming distance was set to 23m, allowing for a calculation of clean speed. The 2m subtraction from pool length is due to body length not included in the timekeeping (time taken from feet leave to hand touch). The subjects rate of perceived exertion, RPE, was assessed immediately after the swim, according to the Borg scale [11].

2.2. Statistical Analysis

The data were treated statistically using the SPSS 22 statistical package (SPSS, IBM, Inc.). A p level of 5% was accepted. Repeated measures ANOVA with 3 levels of wave height and 4 strokes were used to test the main effect of strokes and waves on performance, sphericity assumed. Post hoc tests were performed using Bonferroni corrections for multiple comparisons. For the repeated measures ANOVA tests of stroke rate, stroke length and stroke index, sphericity could not be assumed and a Greenhouse-Geisser correction was used. Effect sizes were calculated as the difference of the means from flat to medium or large waves divided by the pooled standard deviation.

3. RESULTS

The fastest stroke for group A in flat water was front crawl, followed by head-up crawl, backstroke and breaststroke. For group B, the order was head-up crawl with fins, front crawl and head-up crawl. When introducing medium or large waves, the order of strokes from fastest to slowest was identical to flat-water conditions. Tables **1a** and **1b** show the absolute and relative performances of the five strokes in three wave sizes. The repeated measures ANOVA showed a significant effect of stroke, F(3,23)=108 ($p<0.001$) and wave height F(2,24)=87 ($p<0.001$) but no interaction effect (F(6,20)=2). This means that statistically when introducing waves, the swimming speed is slower and that the 4 strokes perform differently. Post hoc tests show that all strokes for group A were statistically different ($p<0.001$) in the order from fastest to slowest strokes: crawl, head-up crawl, backstroke and breaststroke, except for head-up crawl and backstroke which were not different. Post Hoc tests for wave size show significantly slower velocity in medium waves compared to flat and in large waves compared to medium and flat ($p<0.001$, Bonferroni adjusted for multiple comparisons).

Table 1a. Mean ± standard deviation, and effect size (d) of swimming performance in flat, medium and large waves. Absolute values (times) and relative to flat (=1.00).

Stroke	Wave Size	Times (s)	Relative of Flat (%)	d
Breaststroke	Flat	21.21 ±3.10		
	Medium	21.79 ±3.18	1.029 ±.064	.18
	Large	22.99 ±3.44	1.085 ±.063	.54
Front Crawl	Flat	15.44 ±2.03		
	Medium	15.56 ±1.99	1.010 ±.068	.06
	Large	16.81 ±2.50	1.089 ±.064	.60
Head-up Crawl	Flat	17.30 ±2.56		
	Medium	18.20 ±2.99	1.051 ±.060	.32
	Large	19.56 ±3.22	1.013 ±.0.83	.78
Backstroke	Flat	18.12 ±2.40		
	Medium	18.61 ±2.34	1.029 ±.051	.21
	Large	19.49 ±2.69	1.075 ±.048	.54

Table 1b. Mean ± standard deviation and effect size (d) of front crawl swimming performance in flat, medium and large waves. Absolute values (times) and relative to flat (=1.00).

Stroke	Wave size	Times (s)	Relative of Flat (%)	d
Crawl	Flat	16.48 ±2.76		
	Medium	17.38 ±3.29	1.052 ±.034	.30
	Large	17.22 ±3.11	1.044 ±.060	.25
	Flat	18.68 ±4.14		
Head-up Crawl	Medium	19.73 ±4.54	1.055 ±.0.53	.24
	Large	19.41 ±3.75	1.046 ±.046	.18
	Flat	15.97 ±2.80		
Head-up Crawl Fins	Medium	16.31 ±2.89	1.030 ±.064	.12
	Large	16.49 ±3.23	1.022 ±.056	.17

For statistical differences please refer to the text.

Looking at the relative values (*i.e.* flat conditions set to 1) of each stroke, there was no significant effect, but for wave size there was a mean difference in relative velocity decrease of 0.065 ($p<0.001$).

For group B the strokes crawl, head-up crawl and head-up crawl with fins were compared. Head-up crawl with fins was significantly faster than crawl and head-up crawl ($p<0.01$), and crawl was faster than head-up crawl ($p<0.001$). For wave size in group B, medium and large waves were significantly slower than flat ($p<0.01$ and 0.05 respectively), but there was no difference between medium and large wave trials.

For RPE, a repeated measures ANOVA test revealed no effect of wave height (F(2,50)=2.4. $p=0.10$, but a significant effect for stroke (F(3,75)=13.2. p<0.01. Breaststroke had the lowest value of RPE with 11.7±2.1 for flat, 11.3±2.3 for medium and 12.1±2.8 for large waves. The highest RPEs were evident for head-up crawl with 13.2±3.2. 13.2±3.3 and 13.6±3.1 for flat, medium and large wave conditions respectively. Head-up crawl was thus experienced by the swimmers as more strenuous.

Stroke index was reduced with increasing wave height, F(1.2,29.8)=7.8. p=0.006, and the effect was significant across strokes as well, F(1.5.35.3)=24.6, p<0.0001. Stroke rate was reduced with increasing wave height, F(1.0,25.8)=1.1, p=0.030 and the effect was significant across strokes, F(1.4,5.2)=97.3. p<0.001. Stroke length was not changed with wave height. F(1.1,26.4)=2.2. p=0.13, but the effect of stroke was significant. F(1.2,29.7)=43.4, p<0.001. Table **2** shows a summary of stroke parameters across the different test conditions.

Table 2. Mean ± standard deviation and effect size (d) of stroke index (SI), stroke length (SL), stroke rate (SR) and rate of perceived exertion (RPE) of breaststroke, front crawl, head-up crawl, and back crawl in flat, medium and large waves.

		SI		d	SL (m)		d	SR (min^{-1})		d	RPE		d
Breast stroke	Flat	1.67	±0.44		1.50	±0.24		45	±6		11.7	±2.1	
	Medium	1.67	±0.42	0	1.54	±0.25	.21	42	±7	.46	11.3	±2.3	.18
	Large	1.48	±0.37	.47	1.45	±0.24	.16	43	±7	.31	12.1	±2.8	.16
Front crawl	Flat	1.81	±0.62		1.20	±0.40		82	±22		12.2	±1.9	
	Medium	1.81	±0.66	0	1.21	±0.43	.02	81	±23	.04	12.5	±2.5	.14
	Large	1.52	±0.44	.54	1.10	±0.32	.28	82	±21	0	13.1	±2.6	.40
Head-up crawl	Flat	1.26	±0.41		0.94	±0.31		94	±28		13.2	±3.2	
	Medium	1.25	±0.38	.03	0.99	±0.37	.15	88	±29	.21	13.2	±3.3	0
	Large	1.03	±0.32	.63	0.87	±0.28	.24	90	±25	.15	13.6	±3.1	.13
Back crawl	Flat	1.55	±0.52		1.21	±0.39		69	±18		11.9	±2.4	
	Medium	1.55	±0.46	0	1.25	±0.40	.10	65	±18	.22	11.4	±2.1	.22
	Large	1.42	±0.47	.26	1.19	±0.38	.05	66	±18	.17	12.4	±2.2	.22

4. DISCUSSION

The main finding in this study was that when introducing medium waves, a mean performance decrement across all strokes of 3.0% and with large waves of 6.6% was registered (group A). For group B the performance decreased on average 4.5 and 3.7% for medium and large waves respectively. The reversed pattern for group B is not significant, and can be partly explained with a relatively small group size. Effect sizes (d) can be said to be medium if above 0.5 or large if above 0.8 [12]. All large wave trials in group A have a d larger than 0.5 but below 0.8 and are thus of some or medium importance, however for all trials in medium waves and for group B, the effect sizes are small. Waves of height 20-40cm seem thus not to be of great importance when sprinting for 25m, however for larger waves (40-60cm) speed is affected significantly and clinically relevant. Head-up crawl had the largest effect size for large waves (0.78), and the largest decrease in relative velocity. This stroke seems to be strenuous to use in waves, and should be used with a reflection that this might be a disadvantage in a lifesaving setting. However, head-up crawl has other more positive traits, to be discussed later in this paper. Furthermore, although the effect size and magnitude of velocity decrease seem small or moderate, this is for a 25 m sprint, and moving a longer distance, might lead to more important differences. For a 200m trial with children, Kjendlie *et al.* [4] found an 8% reduction in performance, indicating that for longer distances the velocity decrease is augmented.

A slower speed when swimming in an unsteady water surface is not surprising. There seems to be only a few other papers discussing this effect in previous studies. The performance decrement in magnitude is comparable to a study conducted on lifeguards, where pool swimming, when compared with swimming in calm sea and surf [3]. Compared to pool swimming, experienced lifeguards swimming outdoors in calm sea experienced reduced performance by 11.7%, the difference from pool swimming to outdoor surf swimming was 29.9%, and the difference from calm to surf outdoor swimming was 16.3% [3]. For the lifeguards inexperienced in surf, the reduction in performance was about the same going from pool to calm outdoors, at 10.3% but larger from calm to surf and from pool to surf with 42 and 56.6% respectively. These results show that there seems to be an additive effect, since introducing waves in a pool reduces performance, going from pool to outdoors reduces performance and adding surf to an outdoor setting worsens the performance accumulatively.

Few, if any, have investigated the performance or effectiveness of different strokes in unsteady water. The debate of which stroke to use in different conditions can thus, so far, not be backed up by empirical data. Our data show no shift of rank between the strokes when introducing medium or large waves, breaststroke was still the slowest, and front crawl still the fastest. Backstroke and head-up crawl switched order in large waves. There is no stroke that has an increased performance advantage over other strokes when waves are present, compared to flat conditions. The largest and second largest decrement value in velocity in large waves was for head-up crawl and breaststroke (n.s). This indicates that strokes with head-up may be losing more velocity in waves. Our group of subjects were competitive swimmers, and it was shown by Tipton *et al.* that there is a clear effect of skill related to the performance decrement going from flat to unsteady water [3]. We therefore hypothesise that with larger waves, and less experienced swimmers, the effect of a slower performance in waves for strokes with head-up would be detected. Future research are needed to test this hypothesis.

Few other studies have compared the effects of swimming with the head up to head down in flat water conditions. De Jesus *et al.* [13] found no difference in maximal speed when comparing head up with head down front crawl. The subjects were water polo players, well accustomed to both styles, and they were tested over only 15 meters. Compared to our 25 m bout, the explanation might be that the 15m was too short to detect fatigue and its effect on performance of the two strokes. The authors found that there was a significant and almost double in magnitude greater trunk angle in head-up crawl than in head down. This should lead to greater drag, and thus slower speed. Possibly, the water polo players were able to compensate in one way or another for the greater trunk angle given that the maximal velocity was not different.

When comparing head-up crawl with head down crawl in young water polo players, Zamparo and Falco [14] found that head-up crawl did require more energy, higher heart rate, a larger trunk inclination and a lower propelling efficiency compared to head down crawl. Although maximal speed was not compared, these are clear signs explaining why head-up crawl is a slower stroke, as we found both in flat, medium and large waves. Similarly, Stallman *et al.* [15] compared the energy cost of swimming breaststroke (head up only during breathing) with head-always up-breaststroke. The results show that normal breaststroke demands significantly less energy compared to head-always-up-breaststroke ($p<0.001$). These studies strengthen the belief that head-up stokes are less economical.

Stroke rate and stroke index were all found significantly decreased with increasing wave height, however, the effect sizes are only in the medium zone for front crawl and head-up crawl in large waves. Stroke length was not significantly reduced with waves, and showed only small or no effect sizes. From these measurements, it seems that, as waves are introduced, a reduced velocity is due to a reduced stroke rate and that stroke length contributes less to the change. Already in 1985 Costill *et al.* [16] proposed a close relationship between stroke index and energy consumption during swimming. The reduced SI when swimming in waves can be interpreted as a sign of worsened economy, *i.e.* the swimmers use more energy to cover a given distance.

The perceived exertion or strenuousness did not change statistically in medium and large waves. This means that the swimmers consider it not more strenuous to swim in waves compared to flat water. Although not statistically different, nor any effect size of importance, there is a weak trend observable of a ca 0.5 unit increase in RPE from flat to large waves. We believe that a longer distance, and perhaps larger waves could clarify this in future studies. RPE was however different across the strokes, breaststroke had lowest RPE, while head-up crawl evidenced the largest values and were experienced by the swimmers as more strenuous. This should be taken into account when choosing strokes in a lifesaving setting.

4.1. The Different Strokes´ Advantages and Shortcomings in a Lifesaving Setting

Our results comparing different strokes in flat, medium and large waves show a consistent (flat water) order of performance also in waves. However, there are other aspects of swimming in an outdoor setting, with unsteady water and in a lifesaving or self-rescue setting. Apart from performance (velocity), the strokes have some advantages and shortcomings. Table **3** is an attempt to summarize this.

First, if we focus on self-rescue, when speed of swimming is important, front crawl is most effective. Performance in terms of covering a distance in a short time, and at the same time offering a reasonable energy cost can be important. The fastest stroke was front crawl followed by head-up crawl, backstroke and breaststroke. Other authors found head-up crawl to be slower than head down crawl [13, 14]. For the order (fast to slow) of front crawl, back and breaststroke, this is documented by numerous studies (*e.g* [8].) as well as the world records of competitive swimming. Drag was found to be less in front crawl than in backstroke, and less for backstroke compared to breaststroke [17]. No studies seem to have investigated efficiency when swimming in waves. For flat water, several authors report similar findings for velocity and drag, front crawl being the most effective, followed by back and breaststroke. Klentrou and Montpetit investigated the energy cost of backstroke, compared the results to other studies and concluded that front crawl is slightly more effective than backstroke, costing less oxygen at a similar velocity [18]. Compared to breaststroke, front crawl has greater propelling efficiency, less drag and less oxygen cost [7, 19].

Secondly, other aspects of a stroke chosen for self-rescue or lifesaving outdoors should be considered. One trait of swimming strokes is the ease of orientation – where to look and swim in sea or in a lake, with no guide from a pool wall, bottom or lane rope. Clearly front crawl here has a disadvantage, having the head down, while breaststroke and head-up crawl have potential for good orientation, you can look in the swimming direction and look for a victim that is to be rescued. It is common to observe outdoor swimming competitions (triathlon or open water) where the contestants swim front crawl (head down) but occasionally lift their head up. Cicciarella [20] found that breaststroke lost less speed when blindfolded compared to front crawl. The reduction of velocity when blindfolded compared to normal sighted swimming was 4.9% for breaststroke and 8.3% for front crawl ($p<0.05$), taken as an indication that breaststroke is a less complex stroke than front crawl [20]. However, we believe that other causes for this difference should be examined, and that breaststroke is not necessarily less complex than front crawl. Backstroke has no forward visibility, but can be useful when looking backwards to a fixed point on land to keep the right direction or to observe a victim or a hazard.

Another trait of the strokes we compared is the ease of breathing, and can be viewed in the same manner as orientation. Head-down strokes need a head lift, or body rotation to clear the mouth from the water. This interrupts the swimming rhythm, and may cause swallowing of water; and the swimmer cannot see waves coming. The disadvantage of front crawl can be that side-ways or rotary breathing may cause a danger for swallowing water during unsteady conditions. Furthermore, such breathing actions demand a certain skill level. Breaststroke allows for a more controlled breathing as you can see where you are going and calculate the random waves more accurately in coordination with inhalation of air. Head-up crawl needs a head lift to breathe, requiring a certain skill, but also disrupts the body alignment and slows velocity. Clearly backstroke has the great advantage of letting the swimmer breathe freely, however random waves can appear over the head and cause swallowing.

Finally, the swimmer's skill and experience need to be considered when choosing the best stroke to use in an outdoor or lifesaving setting. Tipton *et al.* found a clear skill component when performing in surf [3], but there are only a few studies that seem to have investigated which strokes are easier to learn or perform. One indication is given by Cicciarella, who claims that breaststroke may be less complex to learn than front crawl [20], based on maximal attainable distance, maximal floating time and speed to cover a distance. However, the question of which stoke is more complex, which strokes are more easy to learn and which strokes require less skill in a lifesaving or self-rescue setting supported with empirical data, is quite a challenge. We believe that this question is far from solved and requires further studies.

Statistically the swimmers did not experience larger waves as more strenuous. This may be considered unexpected, however, the subjects were competitive swimmers, and were asked to swim at maximal effort in any condition. The result is a good indication that they did perform maximally, and that introducing waves resulted in the same experienced fatigue, but it caused the velocity to decrease. The purpose of this paper was to investigate the performance of each stroke in waves. How fatigue would play a role in longer distances needs another design and needs to be addressed in the future.

Table 3. Summarizing traits, advantages and shortcomings of several strokes.

	Speed [a]	**Economy**[b]	**Orientation**[c]	**Free Breathing**	**Skill (Difficulty)**[d]
Front Crawl	+++	+++	0	0	+
Back Crawl	++	++	+	+++	++
Breaststroke	+	+	+++	+++	+++
Head-up Crawl	++	+	+++	++	+++

[a] from the present results [b] references for the economy [7, 14, 21], there are no studies comparing breast with head-up crawl, so their internal rank of economy cannot be addressed. [c] meaning how easy it is to look for obstacles or to look for the direction to swim [d] this is a matter of the authors opinion

The subjects recruited for this study limit the results to this cohort, and conclusions about the more general public, other age groups or persons with less skill would need future study. The design also limits the results to short distance and duration, as well as to the used wave type (in contrast to for instance, longer and more systematic “beach” or breaking waves).

CONCLUSION

The order of performance in waves is the same as in flat water. There are no indications of a stroke that performs relatively better in waves compared to flat water, and the choice of stroke to use in self rescue or the rescue of others should be made with different traits of the strokes in mind, such as ease of breathing, orientation and skill level required.

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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