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SEARCHING IN JUSTIFICATION FOR THE INTENSIFICATION OF UPWARD-KICKING IN DOLPHIN SWIMMING

Marek Rejman[1)], Daria Rudnik[1)], Wojciech Seidel[2)], Piotr Siermontowski[3)]

[1)] Department of Swimming, Wroclaw University of Health and Sport Sciences, Poland
[2)] Department of Paralympic Sports, Wroclaw University of Health and Sport Sciences, Poland
[3)] Department of Underwater Works Technology, Naval Academy, Gdynia

ABSTRACT

Scientific opinions about the importance of dolphin upward leg movements for swimming performance are still divided. Research on the efficiency of propulsion, similarly generated by a relatively larger the monofin surface, showed that quality of the upward movement phase is a measure of swimming performance. Therefore, the forces generated as a result of upward and downward kicks in butterfly swimming were analysed. The ability of the swimmers to kinaesthetically control of the upward dolphin kicking was also researched. Ten international level butterfly swimmers (mean 18,2±1,4 years) took part in the research. They performed three trials on 25m distance, at maximum speed using the monofin device (The plate of standard monofin was removed and two strain gauges were affixed in the middle, between the toe). They randomly swam: 1) butterfly stroke (BS), 2) dolphin-kicking only (LK) and 3) swam being focused on activation of upward-kicking (AUK). Time dependent signals of the force sagging the fin in reaction to the water resistance were registered. The impulses of force sagging the fin in each stroke were lower in upbeat than in downbeat. The lowest difference was in AUK trial. First, Wilks's test and then Duncan's post hoc tests for each of the trial showed (at $p \leq 0,05$) that: downward impulses for LK was significantly higher than for BS. Upward impulses did not differ between the trials. Downward times for AUK, the same as total trial times, was significantly longer than for BS and for LK Upward times for AUK was significantly longer than for BS. The results demonstrated, that butterfly arms action leads to intensification of both kicking phases. The swimmers were well skilled for kinaesthetic controlling of the dolphin upbeat. They did not obtain the equal proportion between propulsion effect of both kicking phases, but it has been suggested, that this level of skill mastering is out of the human motor abilities. Opportunities for conscious controlling of the efficiency of the upward movement are seen in the modification of the time structure of this phase. These results could be used for improving the leg-kicking performance in butterfly swimming, as well as after stars and turns.

Keywords: Swimming, dolphin kick, downbeat, kinaesthetic controlling, dynamometry.

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INTRODUCTION

Dolphin kicking is undoubtedly an important determinant of swimming performance, especially in sprint events. The butterfly swimmers swam with the leg-kicking on starting zone at a speed of 25-40%, and in the turning zone, up to 14% faster than the average speed obtained during swimming over the distance [1]. Therefore, this technique is generally performed in start and turns in all the swimming strokes. In this scope, searching for reserves in the propulsion effect of the dolphin-kick seems to be reasonable. Perhaps these reserves lay in the upward-kick activation.

The scientific points of view on the importance of upward-kick for butterfly swimming performance are still divided. It was suggested [1] and justified in studies of positive vortices in both phases of leg-kicking [2], that butterfly swimmers induced much more propulsion in downward leg-kicking than in upbeat. However, it was also shown that butterfly swimmers who were able to perform stronger upbeat - obtained the higher swimming speed [3].

The analyses of forces bending the monofin that are treated as the main source of dolphin-like-kick propulsion showed, that higher values of propulsive forces were generated in the downward-kick than in the upward one [4]. The longer path of foot displacement was also exposed in downward movement. Nevertheless, in the same study, it was stated that activation of the forces generated on the monofin in upward-kick played an important role in obtaining the highest swimming speed. In the presented scope, it is worth checking whether butterfly swimmers are able to use the upward kick to increase the propulsion effect not only during the distance swimming but also in the start and turns.

Controlling the leg-kicking in monofin dolphin-like-kicking is very closely related to the ability to receive and process kinesthetic stimuli delivered by proprioceptors placed in the skin, muscles, and tendons [5]. Hence the next question arises: are highly skilled butterfly swimmers able to self-control the upward kicking in order to employ it to improve their performance?

Only a few studies were carried out on the kinesthetic abilities of monofin and butterfly swimmers in dolphin-kicking. Rejman et al. [5] showed that monofin swimmers have the ability to repeat the forces generated in the water and in dry-land conditions with greater precision than their peers - without any fin swimming experiences. Also, the well-skilled butterfly swimmers showed the skill for kinesthetic controlling of the leg kicking [6]. It means that this ability, named "feel of water" can be trained and developed. This way, controlling upward dolphin-kick propulsion seems to be desirable to improve the swimming technique in order to obtain the best swimming performance not only in the start and turn zone but also in distance swimming.

In this study it has been assumed, that the value of forces generated in time function (impulse) during the downward and upward phases of dolphin kicking, can be treated as a quantitative measure of the dolphin-kick propulsion effect. In the presented context, there is evidence that especially in upward dolphin kicking, the ability for kinesthetic control of the propulsive forces generation, as a qualitative measure of the dolphin-kick propulsion effect, can improve the dolphin kicking performance. Therefore, apart from analysis of the process of propulsive forces generation in butterfly swimming technique (BS) or dolphin kick only (LK), direct diagnosis of controlling activation of upward kick (AUK), will be taken into consideration. The aim of this study was to analyze the process of the propulsive forces production as a result of upward and downward dolphin leg movements. It was hypothesized that skilled butterfly swimmers are able to kinesthetically control their movement during upward kicking and this way they can learn how to use this phase to improve their performance.

METHODS

The sample was composed of ten national-level male swimmers (486 ± 46 World Aquatics Scoring Points) with 18.2 ± 1.2 years of age. The body height (183.13 ± 16 cm) and body mass (74.34 ± 8.6 kg) described the somatic potential of the swimmers. It was assumed that the research group was homogenous considering the body structure and high level of butterfly-stroke swimming proficiency. It should also be mentioned that none of the participants had previous experience with the activation of upward dolphin kicks.

All the procedures were performed in accordance with the 1964 Declaration of Helsinki and its later amendments. The voluntary participants and their parents were informed about the objectives and all procedures of the experiment. Written informed consent for participation in the research was obtained from the adult swimmers and from the legal representatives of all youth athletes. The study was approved by the Ethics Institutional Board.

The experiment was conducted in a short course indoor 25 meters swimming pool (water temperature 27°C, air temperature 29°C, and relative humidity 60%). Before data acquisition,–all participants underwent a familiarization process with the testing device - the prototype of monofin equipped with strain gauges (Figure 1). Next, participants performed their individually preferred warm-up in the water. After ten minutes of rest, the swimmers randomly performed three individual trials of 25 m of swimming using the monofin. It consisted of: 1) swimming with standard butterfly technique (two legs stroke) (BS), 2) swimming with dolphin-kicking only (one leg stroke) (LK), and 3) swimming with dolphin-kicking only with an accent to activate (strengthen) upward-kicking (one leg stroke) (AUK). Enough resting time to achieve total recovery (ten minutes) was assured between each trial. The participants were asked to perform all the trials with possible maximal speed.

Fig. 1 The testing device - Prototype of monofin with plate cut at the toe line and equipped with strain gauges.

The testing device (prototype of monofin) (Figure 1) was used in all the trials. A pair of strain gauges (HBM, Germany) were attached to the monofin at the end of the cut plate, in the middle, and in the symmetry axis of its surface. The raw data collected with the gauges were expressed as voltage time series, and defined as changes in the forces bending the monofin in reaction to water resistance[6]. The scaling procedures of the fin were based on the relationship between registered forces and the degree of the bending of the fin [7]. Impulses from the gauges (sagging fin) were amplified, converted, and recorded at PC with a sampling frequency of 50Hz.

The values of average impulse were estimated from the recorded force-time series for upward and downward kicking and taken for further analyses. Identification of the downward and upward phases was made on the basis of the methodology of analogous measurements taken while swimming with a standard monofin [4]**.** The impulse is the integral of a force over the time interval for which it acts. From the principle of conservation of momentum, it follows that the resultant force arising at the fin surface causes acceleration and a change in the velocity of the swimmer's body for as long as it acts. This force applied over a longer time produces a bigger change in linear momentum than the same force applied briefly. Conversely, a small force applied for a long time produces the same change in momentum - the same impulse - as a larger force. In swimming, due to the high density of water, to achieve maximum speed it is crucial to intensify the generation of propulsive forces in time. Therefore, the average resultant downward impulse (DI) and average resultant upward impulse (UI) were estimated. Also, temporal parameters of the process of propulsion generation - average time of downward-kick (DT) and the average time of upward-kick (UT) were measured for a given trial. The total trial time (TTT) has been also taken into consideration, as a measure of swimming performance.

The analysis of variance for repeated measures test (ANOVA) was used to compare variables extracted from the repeated observations of three different trials defined by the specification of the movements (BS, LK, and AUK). Here, in cases revealed as significant through ANOVA, the Duncan post-hoc test was run to further verify the significance for each pair of trials. Additionally, to assess multiple dependent variables simultaneously MANOVA was conducted. The values of the Pearson correlation coefficient were calculated between the parameters of each trial. Statistical procedures were conducted by using the Statistica 13.1 software (StatSoft, USA), with the level of statistical significance established at $\alpha \leq 0.05$.

RESULTS

The average resultant downward impulse (DI) was much higher than the average resultant upward impulse (UI). The highest difference between these both phases (ΔI) was noted in the leg-kicking trial (LK) (ΔI=70,90%), compared to active upward-kicking (AUK) (ΔI= 49,89%) with similarity to BS (ΔI=44,38%). The average downward time (DT) was longer than the average upward time (UT). In the case of LK this difference was definitely the highest (ΔT=41,45%) In BS this difference was (ΔT=4,20%) with similarity to AUK ΔT=8,80%. The Wilks' test for all the registered parameters in every trial showed significant differences between them (Value=0,165424; F=5,3485, p<0,001; Effect df=12; Error df=44).

Tab. 1

Results of ANOVA for the parameters under research.

	F	p	η^2	(α=0,05)
Upward Impulse	0,701	0,505	0,049	0,1557
Downward Impulse	4,119	0,028*	0,234	0,6789
Upward Time	3,892	0,033*	0,224	0,6526
Downward Time	5,709	0,009**	0,297	0,8232
Total Trial Time	6,508	0,005**	0,325	0,8722

*p≤0,05, **p≤0,009

Comments for Table 2: DI was the highest in LK (29,27 ± 7,39 N·s) and similar to AUK (26,05 ± 10,62 N·s). The lowest value of DI was noted for BS (18,82 ± 6,41 N·s). DI for BS and LK was significantly different. UI was the highest in AUK (10,52 ± 7,73 N·s), the lower for LK (7,29 ± 5,88 N·s) and BS (8,37 ± 4,67 N·s). UI did not differ between the trials. DT was the shortest for BS (0,66 ± 0,21s) and the longest in AUK (DT=1,00 ± 0,31 s). For LK, DT=0,73 ± 0,17 s. DT for AUK was significantly longer than for BS and for LK. UT was the shortest for LK (0,38 ± 0,20 s), longer for BS (0,51 ± 0,19 s), and the longest for AUK (0,75 ± 0,43 s). In UT difference between BS and AUK was significant. TTT was the shortest for BS (17,31 ± 2,05 s), similar for LK (16,99 ± 4,25 s), and the longest for AUK (TTT=22,20 ± 4,13 s). TTT for AUK was significantly longer than BS and LK.

Tab. 2

Duncan's post hoc test for parameters that showed statistically significant differences in univariate significance tests.

	Leg-kicking (LK)	Active upward-kicking (AUK)
Downward Impulse (DI)		
Butterfly swimming	0,012*	0,063
Leg-kicking	-	0,396
Active upward-kicking		-
Upward Time (UT)		
Butterfly swimming	0,3544	0,083
Leg-kicking	-	0,014*
Active upward-kicking		-
Downward Time (DT)		
Butterfly swimming	0,546	0,005**
Leg-kicking	-	0,016*
Active upward-kicking		-
Total Trial Time (TTT)		
Butterfly swimming	0,847	0,005**
Leg-kicking	-	0,005**
Active upward-kicking		-

*p≤0,05; **p≤0,005.

Tab. 3

The values of Pearson's correlation coefficient obtained for the analyzed parameters.

	BS/UI	BS/DT	BS/UT		LK/UI	LK/DT	LK/UT		AUK/UI	AUK/DT	AUK/UT
BS/DI	-0,57	-0,81*	-0,32	LK/DI	-0,55	-0,78*	-0,58	AUK/DI	-0,38	-0,93*	-0,36
BS/UI	-	-0,60	0,68*	LK/UI	-	-0,68	-0,36	AUK/UI	-	-0,48	-0,84*
BS/DT		-	-0,16	LK/DT		-	-0,35	AUK/DT		-	-0,40

*p≤0,05; Notes: BS, butterfly swimming; DI, downward impulse; UI, upward impulse; DT, downward time; UT, upward time; LK, leg-kicking; AUK, accent upward kick.

DISCUSSION

Generally, it was not surprising that in all the dolphin-kicking trials the propulsive forces were produced mostly as the effect of the leg extension in knee joins in downbeat [6]. In AUK ("single-kick") trials the percentage distribution of upward and downward-kick was relatively similar (ΔI=49,89%). It seems that the control of upward-kick propulsion is possible. It is interesting that in BS ("double-kick") trials, the percentage of upward impulse (ΔI=44,38%) was also high and similar to the in AUK. So, probably in BS trials with limited time for two kicks, together with the need to coordinate them with the arms stroke [8] is not conducive for controlling the kicking as much as in legs-only swimming. This limitation of stroke time probably results in relatively higher impulse in this phase. In LK trials, the propulsion was generally produced in downward kick (ΔI=70,90%). It can be understood as, that the swimmers, did not control their upward legs movement in this trial. TTT for AUK was significantly longer than for LK (Table 2), but it could be reasoned by the lack of previous experiences with the activation of upward dolphin-kicks in the researched group of swimmers.

The results (Table 3) showed, that in all the trials higher DI went together with shorter DT, but only for BS and AUK trials, the negative correlation between UI and UT was noted. That means, that the potential rise in impulse and the shortening of the time of its production could be a way for the propulsion increasing of the upward-kick. The mentioned trials differentiated from each other only in DT - significantly longer for AUK than for BS (p_{DT}=0,005) (Table 2). When the values of upward and downward-kick impulses were almost equal, in BS trials swimmers swam significantly faster than in AUK trials (p_{TTT}=0,005) (Table 2). It probably seems that the elongation of the temporal structure of DT has decided on the lower propulsion effect in AUK. These findings are also visible in comparison to the results obtained for LK and AUK trials. LK trials were significantly faster than AUK trials (p_{TTT}=0,005) because of the highest DI, significantly higher than in AUK (p_{TTT}=0,012) and significantly shorter DT (p_{DT}=0,016), with the same range of UI and significantly shorter UT (p_{UT} 0,016) (Table 2). Thus, it seems that in this set of trials, the lower propulsion effect in AUK was determined by the elongation of UT. In this scope, it can be suggested that in AUK trials (focused on the equal up and down-beat), potentially the highest impulse together with the shortening of the time of its production supports the propulsion effect of the dolphin-kicking.

In butterfly stroke, the intra-cycle velocity decreases during the arm's recovery and the hand's entry. Underwater dolphin-kick swimming in streamline position is more efficient [8]. Therefore, this technique is used after the start and turns in all the swimming strokes. In this scope, there are no doubts about the need to research the reserves in dolphin leg-kicking.

In the previous studies, well-skilled swimmers were also able to kinesthetically control the dolphin upbeat, even though they did not obtain an equal proportion between the propulsion effect of both kicking phases [6]. Then, assuming that swimmers are able to control the upward-kicking by engaging their kinesthetic sensation, the coach intervention can change the technique in order to improve the swimming performance.

Searching ways for improving the trust provided by upward-kicking it is crucial to note that asymmetrical mobility of the knee and ankle joints limits the thrust production in this phase [9]. Thus, a foot motion, ankle flexibility, and knee flexion have a large impact on upward-kick performance [9]. If the feet move upward with dorsal flexion, water flows around the monofin (or feet) with no thrust production. Too extensive knee flexion is unreasonable, because the calf displacement in the swimming direction produces the drag [4]. Additionally, excessive knee flexion and dorsal foot flexion would make it difficult to transfer the vortex toward the monofin (foot). If the vortex flows down and is not released backward by the fin (feet), opposite to the swimming direction [4] or less destruction of the vortex would deprive a swimmer to "reuse" the energy of the previously shed vortex [10] – propulsive thrust would not increase. Thus, regarding monofin-kicking, keeping the maximal plantar flexion of the feet together with the limitation of legs flexion in knee joints become the key-element in controlling the bare feet upward-kick.

It is also important that increasing the propulsion effect of the upward-kick (activation and boost of the impulse with a shortening of the time of its production) has to be controlled in order to keep the rhythmical up and down leg movements. It is crucial for the fastest butterfly [11] and monofin swimming [4]. In the case of upward-kick after the start and turns, it is fostered by immersion of the swimmers, when the kicking with the optimally longest amplitude is not limited by air-entrainment, and surface waves [9].

The analogies between bare-feet-kicking and monofin swimming are rather clear but it can raise some doubts in case of the limitations of this study. Generally, it has been justified by the fact that the feet are responsible for most of the thrust production and that other parts of the leg do not contribute directly to propulsion [9]. Besides the reasons mentioned previously, numerous experiments with the active forces in dolphin-kicking have been described, but the scientific sources, where the propulsive forces were directly measured on the 'propelling surfaces' have been only available for monofin swimming. Another limitation arisen from the approach, is that leg-kicking was analyzed only in terms of the source of propulsion – the reaction forces measured between the feet. The knowledge concerning the effects of this process (i.e. stroke rate, stroke length, and stroke index) has to be also provided in future (with the larger sample group). Let the analogical example from professional cycling, when one leg pushes the crankset (pedal), and the second one pulls it in order to increase the efficiency of propulsion make visible the message of this study.

There is evidence that for controlling the upward phase in dolphin kicking the swimmer conscious action is necessary. It can be treated as the aim of coach intervention focused on improvement of the kicking technique in start and turns. The following directions of the technical training changes can be suggested: activation (increase) of the impulse with a shortening of the time of its production as a way for increasing the propulsion effect of the upward-kick, and keeping the maximal plantar flexion of the feet together with the limitation of legs flexion in knee joints as the key-element in controlling the upward phase of dolphin-kick.

In butterfly swimming leg kicking seems to be not conducive for controlling, but the limitation of the stroke time resulting in relatively higher impulse in this phase.

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dr hab. Marek Rejman, prof AWF
Zakład Pływania, Wydział Wychowania Fizycznego i Sportu
Akademia Wychowania Fizycznego we Wrocławiu. Ignacego Jana Paderewskiego 35
51-612 Wrocław
Tel: +48 71 347 3440, Fax: +48 71 347 3450
e-mail: marek.rejman@awf.wroc.pl