Study of the motor mechanisms of the underwater phase of the start of a para-swimmer with unilateral lower limb deficiency

UDC 796.015+797.21

PhD, Assistant Professor **L.V. Vinokourov**[1]
PhD **A.L. Lebedeva**[1]
I.A. Baymuratov[2]
J.A. Kaipov[2]
[1]Saint-Petersburg scientific-research institute for physical culture, Saint Petersburg
[2]Nukus Branch of Institute for Retraining and Advanced Training of Specialists in Physical Culture and Sports, Nukus, Uzbekistan

Corresponding author: skorobey64@mail.ru

Received by the editorial office on 16.06.2025

Abstract

Objective of the study is to identify and describe the mechanism of underwater wave-like swimming in swimmers with unilateral lower limb deficiency.

Methods and structure of the study. Video recording of the underwater phase of the start and analysis of video materials, stereoscopic analysis of movements with measurement of fluid flow velocity and vortex formation, assessment of the range of rotation of the leg joints, mathematical and statistical methods were used.

Results and conclusions. It has been established that the mechanism of propulsion in the underwater phase after the start in swimmers with lower limb deficiencies differs from that in healthy swimmers in that they are unable to generate paired vortices and move by releasing a vortex created by only one leg. At the same time, a large vortex around the foot is created when striking downwards, and a small one when striking upwards. The range of hip rotation in swimmers with an amputated leg is smaller than in healthy swimmers.

Keywords: *swimming, underwater start phase, para-swimmer, unilateral lower limb absence.*

Introduction. World Para Swimming rules allow the use of underwater propulsion in swimming competitions for a distance of 15 meters from the wall after the start and after the turn. In this section, most swimmers use a wave-like body movement technique called underwater undulation swimming (UUS) [5] or 'diving'. In healthy swimmers, UUS results in pairs of vortices being generated by the movements of both legs, which collide with each other during the internal and external rotation of the hip joint to generate greater momentum and thus provide the driving force in the underwater phase [3, 7, 9]. In this regard, it has been shown that hip and ankle joint rotations are necessary for the collision and release of vortex pairs generated by both legs [7, 9]. This fact implies that the mechanisms of propulsion may differ between healthy swimmers and swimmers with a missing lower limb who perform movements with only one leg.

The mobility of the swimmer's foot is particularly important for the effectiveness of movements in the UUS phase. Therefore, it seems appropriate to assess small-amplitude oscillations of the ankle joint from side to side (inversion, eversion), the range of flexion, extension, abduction and adduction angles of the foot. Paraplegic swimmers with a deficit in one leg begin the movement by moving the intact lower limb up and down, while maintaining the correct body position with both arms raised. However, it remains unclear what kind of vortex is generated around the paraplegic swimmer's intact leg and what momentum is gained during these movements.

Objective of the study is to identify and describe the mechanism of underwater wave-like swimming in swimmers with unilateral lower limb deficiency.

Methods and structure of the study. Understanding the specific propulsion mechanism will help coaches and instructors effectively select a set of corrective measures to increase the swimmer's speed in the underwater phase after the start. Foreign studies have also attempted to elucidate the propulsion mechanism by visualizing the flow around a healthy swimmer using 3D-PIV software [5, 6, 9]. The design of this study was implemented using 3D modelling of the movements of a paraplegic swimmer with lower limb amputation with stereo analysis of visual points using Dartfish Pro software. Underwater video recording was carried out with the participation of a para-swimmer (male, MS, height 172 cm, weight 72.5 kg, right lower limb amputation, sports-functional class S9).

The para-swimmer's task was to perform 10 trial UUS (on the chest) in the pool environment with maximum effort, lasting about 10 seconds. Five synchronized high-speed cameras with a motion capture system were installed at the bottom and side walls of the pool. LED sensors were attached to marker points on the swimmer's toes, ankle, knee, and hip joint [1, 4].

In the study, one UUS cycle was divided into eight phases based on the marker positions of the toes, of which four phases involved upward leg movements and four involved downward leg movements. The position of the swimmer's body in the water was taken as the central horizontal axis. Using 3D analysis of video recordings, the amplitude and frequency of the healthy leg kicks, the angles of rotation of the hip, knee and ankle joints, and the vertical speed of foot movements during upward and downward kicks during undulatory movements in the underwater phase were calculated.

To analyze the water flow and measure the velocity of fluid flows, PIVlab software was used, which, based on an instantaneous assessment of the velocity of bubbles, allows the vortex velocity to be measured and the components of the water flow vector around the foot to be assessed in three-dimensional space. MATLAB software and calculations based on equations [8] were used to measure water flow velocity and vortex flows.

Results of the study and discussion. The table 1 shows the processed measurements of kinematic indicators in the underwater phase of the start performed by a para-swimmer with lower limb amputation.

It was found that swimmers with amputated lower limbs move by releasing a vortex created by their remaining leg. At the same time, the actual range of hip rotation was approximately two times smaller than in the results of a study of healthy swimmers [7], according to which the range of hip rotation was 34.24 ±9.45 .

It was also found that at the end of the downward stroke of the left foot, a vortex formed on its dorsal side, which then resorbed. During the upward stroke, a small vortex was observed, its size was insignificant and the water flow velocity was lower than during the downward stroke. A strong water flow around the foot was observed during the downward stroke, in a vertical direction from the middle to the end of the stroke. At the end of the downward kick, a skew (roll) of the pelvis was detected: the swimmer's right hip joint (with stump) was shifted towards the head, and the left hip joint was shifted towards the legs, while the intact (left) leg was located at the level of the central axis of the body.

Along with this, it was determined that at the moment when the para-swimmer moved his healthy leg towards the center of the body, the hip joint of the amputated leg was directed towards the head, and the

Table 1. Average values of kinematic indicators of the S9 class paraplegic athlete during the underwater phase after a ventral start

Kinematic indicators	M±SD
Kick amplitude, m	0,4±0,05
Kick frequency, Hz	1,1±0,13
Maximum vertical foot speed during downward kick in the underwater phase, m/s	1,8±0,2
Maximum vertical foot speed during upward kick in the underwater phase, m/s	1,5±0,13
Range of internal and external rotation of the hip joint, degrees	15,7±6,3
Range of flexion and extension of the hip joint, degrees	19,9±9,1
Range of adduction and abduction of the hip, degrees	6,1±3,5
Range of flexion and extension of the knee joint, degrees	55,1±4,7
Range of inversion and eversion of the foot, degrees	11,5±4,3
Range of plantar and dorsal flexion of the ankle joint, degrees	22,0±2,7
Range of adduction and abduction of the ankle joint, degrees.	23,1±3,7

Note: M – mean value, SD – standard deviation for the sample.

hip joint of the healthy leg was directed towards the foot. We believe that the swimmer moved his foot towards the center of his body by means of lateral flexion movements of the torso, rather than by adducting the hip or foot, and that the range of hip rotation may be less critical for swimmers with one leg than for swimmers with both working legs. Perhaps this was a strategy (unconscious or intuitive) dictated by the need to develop an individual swimming technique for the most effective propulsion using the momentum of only the intact leg. However, the latter requires the setting of a specific task [2], which could potentially be solved in an individual psychological study.

Conclusions. It has been established that a swimmer with a unilateral lower limb deficiency is propelled by the vortex created by only one leg during wave-like movements in the underwater phase, followed by the emergence of a propulsive impulse. Swimmers with lower limb deficits obtain maximum momentum for propulsion in the water at the end of the downward kick. However, the range of rotation (internal and external) of the hip required to generate this propulsive force is significantly less than that of healthy swimmers.

In the future, a comparative analysis of movements and water flows among swimmers with a single leg deficiency who have different swimming speeds in the underwater phase of the start should be conducted, as well as a comparative analysis of swimming speeds in the UUS phase before and after training activities, in order to obtain additional information about the possibilities for improving the starts of para-swimmers with limb deficiencies.

References

1. Belousov S.I., Vinokurov L.V. Primenenie svetodiodnyh indikatorov dlya videoregistratsii i korrektsi i elementov sportivnoy tekhniki plavaniya v sporte slepyh [Application of LED indicators for video recording and correction of elements of sports swimming technique in blind sports]. Adaptive physical education. 2020. V. 82. No. 2. Pp. 35-36.
2. Vinokurov L.V. Spetsialnye zadachi v obshhey psihologicheskoy podgotovke sportsmenov-paralimpiytsev [Special tasks in the general psychological preparation of Paralympic athletes]. Innovatsionnye tekhnologii v sisteme sportivnoy podgotovki, massovoy fizicheskoy kultury i sporta: Sbornik materialov Vserossiyskoy nauchno-prakticheskoy konferentsii s mezhdunarodnym uchastiem, St. Petersburg, October 17-18, 2019. St. Petersburg: FGBUSPbNIIFK, 2019. Pp. 28-32.
3. Mosunov D.F. Voprosy primeneniya vihrevyh dvizheniy zhidkosti v sportivnom plavanii [Application of vortex motions of liquid in sports swimming]. Voprosy sovershenstvovaniya tekhniki plavaniya I metodiki sportivnoy trenirovki plovca: sbornik nauchnyh trudov. NGU im. P.F. Lesgafta. Leningrad, 1972. Pp. 34-35.
4. Patent na poleznuyu model № 203250 U1 Rossiyskaya Federatsiya, MPK A63B 69/10. Svetovoy indicator polozheniya segmentov tela v vode dlya obucheniya sportivnomu plavaniyu: №2020136093: zayavl. 03.11.2020: opubl. 29.03.2021. S.I. Belousov, D.F. Mosunov, L.V. Vinokurov [i dr.]; zayavitel FGBU SPbNIIFK.