People’s Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research

UNIVERSITY OF SOUK-AHRAS
Institute of Sciences and Techniques of Physical and Sports Activities

INDIVIDUAL SPORT : SWIMMING

Course Handout

Licence 3 – Semester 5

Instructor : Labar Riad

Lecturer Grade A

PhD in Theory and Methodology of Sports Training

Specialization: Swimming

Academic Year: 2025–2026

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PEDAGOGICAL MODULE DESCRIPTION (LMD SYSTEM)

1. Module Identification

- **Module Title**: Individual sport 1 : Swimming
- **Field**: Sciences and Techniques of Physical and Sports Activities (STAPS)
- **Program**: Sports Training / Aquatic Activities
- **Specialization**: Swimming
- **Degree Level**: Bachelor’s Degree (Licence – LMD)
- **Year of Study**: L3
- **Semester**: S5
- **Teaching Unit (UE)**: Fundamental Teaching Unit
- **Type of Course**: Theoretical (with applied perspectives)
- **Language of Instruction**: English

Teaching Format	**Hours / week**	**Nbr of weeks**
Lectures (CM)	1h.30	15
Practical Classes (TP)	04 h	
Total Contact Hours	77h	

Credits (ECTS): **6 ECTS**

Coefficient: **04**

3. Module Objectives

This module aims to provide students with scientific and technical knowledge necessary for analyzing swimming as a specific physical and sporting activity, characterized by environmental, biomechanical, physiological, and perceptual constraints.

4. Learning Outcomes (Competency-Based Approach – LMD)

Knowledge

By the end of the module, students will be able to:

- Explain the internal logic of swimming as a sporting activity;
- Identify the constraints of the aquatic environment and their impact on motor behavior;
- Understand the energetic, biomechanical, and physiological requirements of swimming performance;

- Describe the principles of balance, propulsion, breathing, and information intake in swimming.

Skills

Students will be able to:

- Analyze swimming techniques using scientific criteria;
- Interpret swimming performance through physiological and biomechanical indicators;
- Use appropriate scientific terminology related to swimming;
- Apply theoretical concepts to training and teaching situations.

Professional and Personal Competencies

Students will demonstrate the ability to:

- Adopt a scientific and analytical approach to swimming performance;
- Integrate multidisciplinary knowledge (biomechanics, physiology, motor control);
- Communicate clearly in academic and professional contexts;
- Prepare for professional roles in coaching, teaching, and aquatic sports supervision.

5. Teaching and Learning Methods

- Lectures supported by scientific references;
- Technical and performance analysis of swimming situations;
- Use of diagrams, videos, and applied examples;
- Guided reading of scientific articles;
- Interactive discussions and case studies.

6. Assessment Methods

Continuous Assessment (40%)

- Written assignments and reports;
- Oral presentations;
- Active participation.

Final Examination (60%)

- Written theoretical exam;
- Conceptual and applied questions;
- Analysis of swimming-related situations.

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General Introduction

Competitive swimming has been marked by a constant progression in swimming techniques and training methods, making it possible to develop increasingly well-adapted programs. The gradual rise in performance levels therefore makes it necessary to continuously refine all aspects of an athlete’s preparation. Mastery of performance development requires a careful examination of theories related to training preparation in order to determine those that best reflect reality and offer future potential. However, the correction and improvement of the training process presuppose the identification of weaknesses and shortcomings through regular and targeted monitoring. Evaluation remains one of the key tasks in ensuring better organization of the training process. The data collected make it possible to monitor the implementation of established plans, to understand the effects of training on the swimmer, and to more precisely plan subsequent work.

According to E. W. Hines (2000, pp. 28–29), swimming involves the most complex series of repetitive and rhythmic movements. It requires the execution of a number of perfectly coordinated actions, engaging more muscle groups than any other intense and repetitive activity. The coordination required to perform smooth and efficient movements is almost inconceivable. Consequently, because the movements and positions associated with swimming are not natural, simply swimming is not enough to improve technique. Merely increasing the duration and intensity of training does not make one swim faster and only improves physical fitness.

To move the body efficiently through water, it is not enough to forcefully turn the arms and legs; on the contrary, one must constantly seek to minimize resistance to forward motion and eliminate disruptive movements. The expert swimmer does not limit themselves to physical effort alone. They feel the water with every arm stroke and constantly seek support (Boullé-Giammatteï, 2010, p. 3). Reaching a high level of practice therefore requires the careful construction of a dynamic, propulsive body. The swimmer is in active contact with the water; each mode or speed of movement at the surface or underwater provides different mobilities and sensations. The swimmer feels the water with their entire body no part is spared or fails to contribute to movement efficiency.

The search for efficiency in propulsive actions in order to swim faster has become a major concern of scientific research and an important objective for coaches. According to Platonov (1988), the pursuit of efficiency leads to an increasing application of management techniques in training supervision. These techniques are intended to ensure optimal application of scientific data that have made it possible to develop competition-activity models proven to be more successful. However, the training of a competitive swimmer is a long and complex process; year after year, the skills that allow them to express their full potential must be developed. Each age group therefore requires a different form of instruction or training. According to Binder (1998, p. 11), children have increased energy needs: in addition to the requirements linked to basal metabolism and physical activity, there are those associated with growth. Energy mobilization pathways are different; children have a greater capacity to work in the aerobic system than in the anaerobic system, which only becomes fully effective at the end of puberty. Endurance therefore forms the foundation of all physical training in children.

The main objective assigned to the theoretical knowledge selected for specialized swimming instruction, within the framework of university training in Sports and Physical Activity Sciences (STAPS) at the University of Souk-Ahras, is to provide the clearest and most objective possible answers to scientific questions related to competitive swimming. These questions structure the logic of the chapters, which can be understood from two perspectives: the first begins with questions related to the specificity of competitive swimming; the second, conversely, starts with the most fundamental questions, forming the basis for understanding the theoretical technical principles and mechanical laws on which these techniques rely. Our interest also focuses on the stages of swimmer development and the requirements specific to each age group. If our objective is to provide a scientific contribution, it is precisely to allow a better understanding of techniques adapted to different swimming strokes and the possible discrepancies between what might seem logical and concrete reality. In our view, in order to intervene effectively in a technique, one must first be capable of analyzing it with sufficient precision and objectivity.

Chapter 1: Swimming Activity Analysis

Introduction

In this first chapter of the literature review, we deliberately focus on the analysis of swimming as an activity, through its internal logic of achieving a measurable performance and moving in an economical manner. This analysis also takes into account the specificity of this discipline and the constraints imposed by the aquatic environment, particularly with regard to its physical characteristics, which require a restructuring of human motor behavior through the search for and creation of more stable support. The aim is to address the various problems posed by the aquatic environment from the perspective of achieving the most complete possible adaptation of the individual to the specific characteristics of this milieu.

To adapt to the constraints of the aquatic environment, the child must modify terrestrial behavior by constructing a new form of balance, through the reorganization of spatial and temporal reference systems and the establishment of new perceptual references (modification of visual, auditory, tactile, vestibular, and kinesthetic information intake), as well as adaptation to new breathing patterns and the implementation of new modes of propulsion.

For this reason, we have chosen this introductory chapter to explain that the nature of physical exercise in swimming simultaneously expresses very specific energetic, physiological, and affective constraints and demands, related to individual characteristics and requiring continuous adaptation. This adaptation can therefore be characterized through long-term programming that necessarily takes into account clearly defined stages in swimmer development.

1.1 Definition of the Activity

Competitive swimming is defined as the action of moving in water, on water, and under water through appropriate movements (Seners & Millet, 2003, p. 189).

By definition, swimming is an essentially technical sport, closer in this respect to golf than to running or cycling. As in golf, dedicating time and effort to learning techniques is sufficient to swim correctly and derive significant benefits (Hines, 2000, p. 2).

Aquatic activity thus belongs to the category of activities in which technique represents a motor production transmitted in a more or less systematic way and reflects a stabilized adaptation to encountered situations.

An adjustment of techniques according to their use must be sought. For example, techniques for swimming fast over 50 meters differ from those for swimming long distances, as well as from the regulated techniques of the individual medley events.

The intention of achieving a measurable performance, expressed by time or distance, highlights the notion of adapting known techniques by selecting the most appropriate form.

In its performance-related component, swimming emphasizes technical mastery more than adaptation to the aquatic environment, which is why swimming techniques are associated with efficiency and thus highlight the concept of motor efficiency (Seners & Millet, 2003, p. 189).

1.2 Specificities of Swimming

Following an essentially utilitarian and recreational social practice, competitive swimming emerged at the end of the nineteenth century. The concern for speed then raised the issue of improving efficiency (useful energy/expended energy), and swimming techniques were gradually regulated in response to swimmers' technical innovations.

The internal logic of this activity is characterized by the pursuit of performance evaluated by time and distance criteria, under more or less regulated conditions. Technical mastery of the four strokes and performance management constitute the foundation of swimming culture. In particular, freestyle is the least codified but fastest stroke, whereas breaststroke, the slowest stroke, is the most regulated. At the same time, energy expenditure at equal speed increases with regulatory constraints.

Thus, the crawl technique used in freestyle events best illustrates the principles of effective action (maximum efficiency). The same applies to back crawl in backstroke events. In contrast to alternating strokes, butterfly and breaststroke—both simultaneous strokes—pose the problem of discontinuity in motor actions, requiring resolution of the contradiction between propulsion and glide. Mastery of these techniques and performance management constitute the basis of specialized cultural and sporting knowledge (Pelayo et al., 2000, p. 21).

The individual can act in the aquatic environment at two levels:

- **Physical laws**: buoyancy (Archimedes' principle), gravity, righting moment, density, pressure, resistance to forward motion, drag, and temperature;
- **Human potentialities**: biomechanical, physiological, psychological, and informational.

Providing the tools for aquatic efficiency requires intervention at each of these levels. Learning aims at acquiring individual autonomy through the organization of combined knowledge into competencies specific to the aquatic environment. Specific competencies emerge, indicating what must be mastered to solve the problems posed by aquatic activity. Interaction between competencies is necessary to resolve learning challenges. According to Seners et al. (2000, pp. 191–192), these competencies correspond to four major principles:

- **Principle 1**: Rebalancing to orient oneself;
- **Principle 2**: Propulsion;
- **Principle 3**: Breathing adaptation;
- **Principle 4**: Information intake to guide action.

1.2.1 Specificity of the Aquatic Environment

The nature of physical exercise in swimming is primarily linked to the particular characteristics of the aquatic environment, which influence energy expenditure. Water has a thermal conductivity 25 times greater and a heat absorption capacity 344 times greater than air. As a result, sweating does not occur in water, and thermal insulation capacity is reduced (Potdevin & Pelayo, 2012, p. 82).

Depending on pool activities, water temperature generally ranges between 24°C and 31°C. The optimal range for lap swimming (26–28°C) may seem high, but body heat dissipates more rapidly in water than in air. Initially, 26°C often feels cool but becomes comfortable after swimming for a short time. Temperatures above 28°C may hinder training, and above 29°C can cause excessive overheating during intense sessions. Conversely, adaptation to temperatures as low as 15°C is easier, provided continuous movement maintains body temperature (Hines, 2000, p. 18).

Thus, typical pool water temperature (around 26°C) creates a favorable exercise environment due to efficient heat dissipation, although cold resistance is reduced. Consequently, prolonged static situations should be avoided during training sessions. Swimmers also tend to accumulate subcutaneous fat, which provides thermal insulation against cooling.

Unlike air, water is incompressible, placing the body in a state of semi-weightlessness. This has respiratory and circulatory consequences. Hydrostatic pressure on superficial veins enhances venous return, improving exercise conditions. Repeated active exhalations in water rapidly affect ventilatory system development (increased vital capacity, maximal expiratory volume in one second, peak expiratory flow, and pulmonary gas exchange efficiency) (Potdevin & Pelayo, 2012, pp. 82–83).

1.2.2 Specificity of Exercise in Swimming

Due to biomechanical parameters, upright movement in water by beginners is characterized by significant energy waste. Resistance to forward motion is high, and the dominant role of the lower limbs leads to high energy consumption. Poor coordination, inefficient motor organization, excessive muscle tone, and parasitic movements further reduce motor efficiency.

Elite swimmers adapt their entire motor behavior to achieve maximum efficiency. Their energy expenditure is strictly functional, minimizing non-contributory movements. Technical skill directly influences energetic adaptation, and swimmers can organize optimal pacing strategies to meet performance demands (Chollet, 1997, p. 21).

- **Heart rate ranges**: Maximal heart rate in water (220 – age ±10, Astrand) is 10–15 beats·min^{-1} lower than on land (Bassan's law). Training intensities based on heart rate should therefore be reduced by about 10 beats·min^{-1}. For example, for a 16–18-year-old swimmer, the anaerobic threshold corresponds to approximately 160–175 beats·min^{-1}.
- **Maximal oxygen uptake (VO_2max)**: Emphasis on upper-limb propulsion from a horizontal position specifically develops VO_2max. Charbonnier (1974) showed that the ratio of VO_2max measured during upper-limb exercise relative to lower-limb exercise was higher in swimmers (90%) than in non-swimmers (70%). This confirms that VO_2max is specific to the muscle groups predominantly trained and is meaningful only when measured in real activity conditions. However, semi-weightlessness and horizontal positioning reduce VO_2max in swimming compared with upright cycling exercise (Pelayo et al., 2000, pp. 83–84).

Table 1. Oxygen consumption and heart rate (constant speed 1 $m \cdot s^{-1}$) in the four swimming strokes for a university swimmer. (Costill et al., 1994, p. 14)

Stroke	**O_2 consumption ($L \cdot min^{-1}$)**	**Heart rate ($beats \cdot min^{-1}$)**
Freestyle (crawl)	1.83	125
Backstroke	2.42	138
Butterfly	2.85	150
Breaststroke	3.42	162

- **Decrease in speed as a function of distance**

Energy system involvement primarily depends on exercise duration, as in other sports. However, speed reduction with increasing distance is less pronounced in swimming than in running. Studies of world records show that runners lose 30% of speed within four minutes, while swimmers lose 22%; after 15 minutes, runners lose 37%, swimmers only 25% (Potdevin & Pelayo, 2012).

Therefore, training intensity and speed definitions cannot be directly transferred from running and require swimming-specific tools. At least four parameters must be defined in training sets: distance or duration, number of repetitions, duration and type of recovery, and especially intensity or swimming speed. A fifth technical parameter related to stroke length control also requires particular attention (Potdevin & Pelayo, 2012, p. 84).

1.3 Control and Information Processing

In swimming, the mere fact of being in a liquid environment and in a horizontal position is enough to modify information intake. Visual information is less precise than in a terrestrial environment; however, it remains essential for the “steering” of the human body.

As visual function decreases, kinesthetic cues increase. The swimmer must try to perceive the actions he or she produces on the water in order to move forward. Therefore, the swimmer must feel their action on the water and the effects produced on their displacement. To do this, all feedback information is combined, particularly visual, tactile, and proprioceptive information.

Information is highly specific in swimming, particularly because the swimmer must reorganize previous reference frames around a mode of locomotion with a horizontal orientation. Swimming is a physical activity practiced in an unusual environment. Nevertheless, it is a closed, cyclic motor skill, performed in a stable environment without uncertainty. The swimmer must adapt to the new constraints inherent to the logic of the aquatic environment and reorganize motor behavior based on specific information intake.

The transition to a horizontal position, which implies the loss of solid tactile supports and immersion of the head (leading to reduced visual and auditory information), therefore enhances proprioceptive information (Pelayo et al., 2000, p. 237).

1.3.1 Exteroceptive Information

In our usual terrestrial motor behavior, our privileged relationships with the environment are mainly visual and auditory, but the most solid contact with the surrounding world is linked to plantar supports. Indeed, even without visual and auditory information, we remain firmly connected to the ground through the soles of our feet.

The beginner swimmer, even when immersed up to the neck, maintains the predominance of visual and, to a lesser extent, auditory information. Above all, they temporarily retain contact with the ground; they therefore remain dependent on the environment, and their privileged relationships are exteroceptive (sensory receptors related to the external world are located at the periphery of the body: eyes, outer ear, tactile receptors, etc.).

The experienced swimmer no longer has solid contact with the surrounding world and is autonomous in this environment. When swimming freely, visual and auditory information is greatly reduced, thus favoring proprioceptive relations. Sensory receptors are then related to the external world but located inside the body (muscles, tendons, neuromuscular spindles, joints, vestibular systems, etc.) (Chollet, 1997, p. 21).

Exteroceptive information allows the swimmer to gather information about the external world.

1.3.1.1 Visual Information

Water distorts vision, and its chemical maintenance for sanitary reasons can sometimes be aggressive for the eyes, hence the need to wear swimming goggles to better orient oneself in the environment (Seners & Millet, 2003, p. 193).

Visual information is therefore modified during immersion and the transition to a horizontal position. Vision becomes blurred, the visual field is laterally limited, and peripheral vision is reduced. Visual information intake, which is direct and parallel to displacement during terrestrial locomotion, becomes indirect and most often perpendicular to displacement. This information, limited to the visual field, allows the swimmer to situate body displacement relative to a standardized environment (lane markings on the pool bottom and sides).

It should be recalled that depending on the type of motor skill, visual function is essential both for learning and for normal execution of the skill. This is the case in team sports, for example, where the ball, teammates, and opponents are in continuous motion; visual function cannot be suppressed. This is referred to as an open skill, since the environment is variable. In contrast, closed skills are those performed in a standardized and stable environment, such as a track in athletics, a high bar in gymnastics, or a swimming pool. In such cases, visual function plays a role of control, comparison, and verification, with a more or less reduced loss of performance.

Other factors also reduce visual function. In most swimming situations, gaze orientation is not always aligned with the direction of movement. For example, in freestyle, gaze orientation is oblique with a tendency toward vertical. Visual information intake is therefore indirect; the swimmer does not look where they are going, yet visually controls their displacement (Chollet, 1997, pp. 43–44).

Visual control can also be lateral, for example to observe other swimmers. In backstroke, visual reference points depend more than in other strokes on material conditions. Outdoors, the absence of ceiling references requires perceptual adaptation, as in “sunflower” pools where references may be misleading. Visual receptors that gather distant information (tele-receptors) also play an active role in anticipation mechanisms. Initiating a turn requires visual reference points: on the pool bottom for ventral strokes, on overhead flags for backstroke, or laterally through changes in lane-line color (Pelayo et al., 2000, p. 237).

1.3.1.2 Tactile Information

Mainly transmitted through the hands and feet, tactile information is a constant and essential source of information, even though supports are unstable (Pelayo et al., 2000, p. 237). The contact of water on the skin and body, its flow, and its resistance during support phases are important elements to consider (Seners & Millet, 2003, p. 193).

1.3.1.3 Auditory Information

Sounds are altered in water; those produced by motor actions, such as water entry, can be used to evaluate certain actions (Seners & Millet, 2003, p. 193). Auditory information is constantly maintained as a complement to distant exteroceptive information. Even though it plays a secondary role except for visually impaired individuals it is useful in certain specific emergency situations (danger alerts) or pedagogical contexts (oral technical instructions). Gustatory and olfactory information has no significant role (Pelayo et al., 2000, p. 237).

1.3.2 Proprioceptive Information

The beginner who wishes to move in a liquid environment can initially only rely on bodily experiences from land and attempt to adapt them to water in other words, they “walk” in water. However, sensations such as resistance of the liquid medium and fluid supports with the arms are new. Thus, they have no specific reference based on prior experience; everything is new, and they must construct their bodily relationship with the environment from scratch.

The experienced swimmer, on the other hand, has developed this relationship through learning. Their sensations are refined and controlled. They can perceive the position of their body segments relative to each other and to the water, know the exact position of their body, perform specific actions (such as flip turns), control the quality of supports for displacement, and integrate timing during movement relatively well (Chollet, 1997, p. 20).

Proprioceptive information provides information about the body or the body’s position in space through sensory receptors.

1.3.2.1 Kinesthetic Information

Kinesthetic (dynamic) or statesthetic (static) information comes from receptors located in muscles, tendons, neuromuscular spindles, and joints. In water, kinesthesia is distorted due to buoyancy and resistance to forward movement (Pelayo et al., 2000, p. 237). Balance information: the horizontal position and the upward force exerted by the medium—"vertical, directed from bottom to top and equal to the weight of the displaced volume of water" according to Archimedes' principle profoundly modify the usual balance of terrestrial movement (Seners & Millet, 2003, p. 193).

1.3.2.2 Labyrinthine Information

Labyrinthine information, both static (from the saccule and utricle) and dynamic (from the three semicircular canals), requires a complete reorganization of habitual reference points (Pelayo et al., 2000, p. 237).

1.4 Performance Requirements in Swimming

The objective is to identify, among the fundamental qualities required for any sporting practice (morphological, organic, psychological, sociological), those that are specifically demanded by swimming. This involves determining the factors whose interaction conditions the swimmer's state at the moment of peak performance.

According to Cazorla et al. (1984, p. 185), performance considered here as the main criterion of this state is closely dependent not only on training but also on all the factors that have influenced or continue to influence this state. The author distinguishes three types of factors: static, dynamic, and specific.

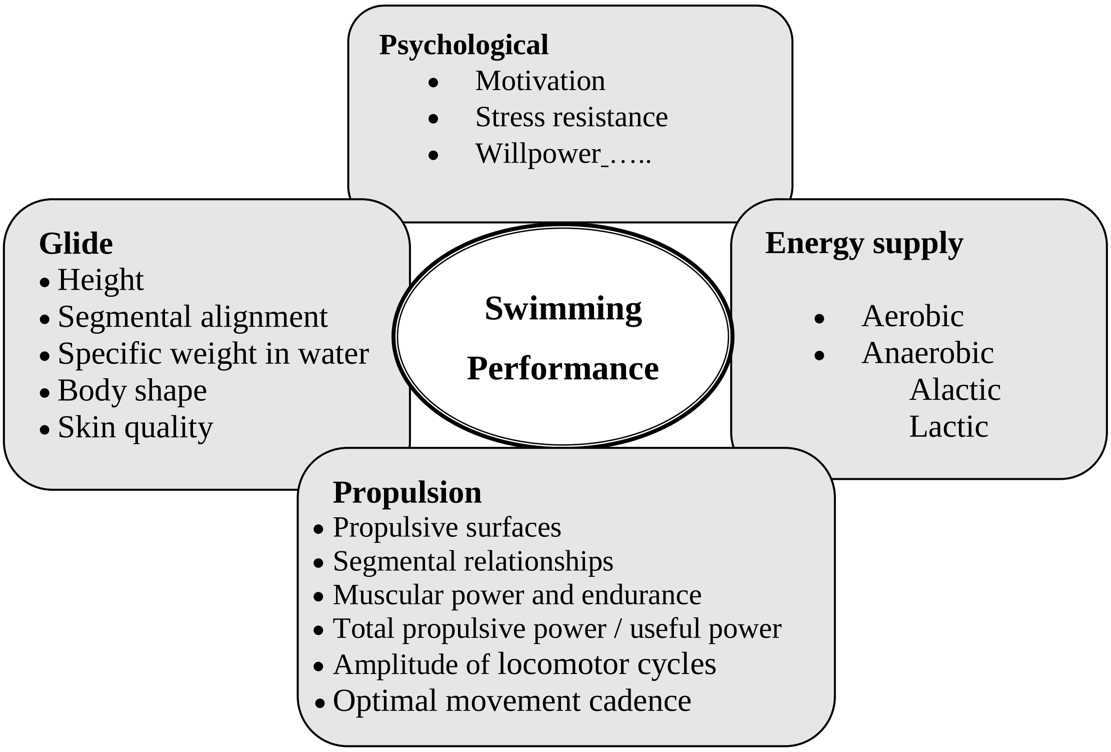

Figure .1: Interaction of the different components of swimming performance
(G. Cazorla, 1994, p. 106)

➤ **Static factors**

These include data that are partly genetic in nature and partly related to the swimmer's medical, sporting, sociological, and psychological background, belonging to the swimmer's past.

➤ **Dynamic factors**

These are the factors that have a direct influence on the swimmer's state of fitness or lack thereof: lifestyle habits, environment, and above all training.

➤ **Specific factors**

A high-level swimmer is first and foremost an athlete with harmonious physical development, presenting no contraindications to intensive practice. They must also possess optimal buoyancy and body dimensions that allow a reduction in resistance to forward motion and make propulsion effective. This propulsion must be maintained at maximum intensity for as long as possible, which requires optimal energy supply. Buoyancy, body shape, propulsion, and energy supply therefore appear to be the determining factors for swimming success, provided that the swimmer's level of motivation, resistance to stress, and willpower are commensurate with these biological qualities.

1.4.1 Morphological characteristics of swimmers

Knowledge of swimmers' morphotypes has become essential today for orientation, selection, and training monitoring. Examinations carried out on swimmers selected for national teams from various countries have shown that success in a given swimming style and over a given distance depends on the specific morphological and physical preparation characteristics of each athlete.

These examinations, conducted by several authors (Boulgakova, 1990; Grimston & Hay, 1986; Pyne & Sharp, 2014), show that sprinters are the tallest and heaviest swimmers. Their total body surface area is larger and, consequently, their vital lung capacity is greater. They are therefore better suited to speed and strength work during the anaerobic phase of swimming. Distance swimmers, on the other hand, are generally not very tall and rather slender. Their highly hydrodynamic morphology favors work in the aerobic phase of swimming.

Backstroke specialists are also among the tallest swimmers, but proportionally their body surface area is smaller, whereas butterfly swimmers tend to be shorter than the former. Likewise, swimmers' body weight varies according to specialization. Breaststroke specialists are the heaviest, followed by butterfly swimmers, while backstroke swimmers, despite their tall stature, are the lightest (Boulgakova, 1990, pp. 7–9).

According to Taiar et al. (1999), unlike results observed in freestyle, height in butterfly does not appear to be a determining factor in swimming speed. Speed is more closely related to body surface area and body weight than to segment length. Breaststroke swimmers, among others, are the shortest, but proportionally have a larger body surface area.

According to Chatard (1998, p. 37), height reflects both positive and negative factors. In sprint events, height is advantageous for starts and turns and represents a gain simply due to the shorter distance traveled. Greater height is also associated with greater muscle mass and thus a better aptitude for sprinting. From an energy-efficiency standpoint, however, height and weight are disadvantageous factors because they increase hydrodynamic resistance. This explains why smaller swimmers tend to perform better over long distances. In these circumstances, aerobic qualities become predominant, and the need for large muscle mass is less pronounced than in sprinting.

For their part, Ria et al. (1990, pp. 206–210) ranked the different factors contributing to sprint performance. Their results showed that arm length appeared as the primary biometric variable, followed by bi-acromial diameter, lean body mass, and height, which ranked similarly in second position. In another study, Chatard et al. (1987, p. 23) showed that the energy cost of freestyle decreases by 5% in swimmers whose arm length exceeds the average by more than 3 cm, compared with other swimmers of the same height.

Movement efficiency largely depends on the surface area of the main elements of the arm (forearm and hand) and the leg (leg and foot) involved in swimming. The larger a swimmer's legs, arms, hands, and feet, the faster their swimming speed and the shorter the distance over which they are likely to specialize. Calculations of indices characterizing the power of the main levers involved in movement have shown that butterfly, breaststroke, backstroke swimmers, and freestyle sprinters have the highest indices for the shoulder and forearm.

Breaststroke swimmers, butterfly swimmers, and freestyle sprinters are characterized by short, powerful thighs, reflecting the contribution of the lower limbs to swimming speed in these strokes.

Table. 2: Typical swimmer morphotypes by specialization
(Silhouette comparisons of sprinters, distance swimmers, butterfly, and breaststroke specialists)

Stroke Specialization	**Height**	**Weight**	**Body Surface**	**Muscle Mass**	**Notes**
Sprint (all strokes)	Tall	Heavy	Large	High	Optimized for short, explosive efforts
Distance	Medium	Lean	Moderate	Moderate	Optimized for hydrodynamics and endurance
Backstroke	Tall	Medium	Small	High	Streamlined body, longer reach for stroke efficiency
Butterfly	Medium	Medium	Medium	High	Strong upper body for simultaneous arm motion
Breaststroke	Short/Medium	Heavy	Large	Strong legs	Emphasizes leg propulsion, smaller arm stroke

The circumferences and cross-sectional areas of different body parts in high-level swimmers also allow an indirect assessment of their strength capacities, insofar as these sections correspond to muscle groups involved in swimming. In freestyle, a decrease in circumference and cross-sectional values is observed as distance increases. It should also be noted that sprinters have a higher percentage of body fat and greater muscle mass than long-distance swimmers (Boulgakova, 1990, pp. 11–17).

Morphology plays a key role in selection, specialization, and performance optimization. Body shape affects propulsion, drag, and energy efficiency.

Additional Insights:

- Limb length and hand/foot surface area increase propulsion.
- Sprint swimmers often have higher muscle mass and body fat, favoring power generation.
- Long-distance swimmers favor a lean, hydrodynamically efficient body to minimize drag.

Body Proportions and Performance

- **Arm span vs. height:** Longer arms increase stroke length, reduce strokes per lap, and enhance sprint performance.
- **Leg length and kick efficiency:** Strong thighs and calves are crucial for butterfly and breaststroke.
- **Trunk and torso:** Hydrodynamic torso reduces drag; chest width supports muscle attachment for arm propulsion.

1.4.2 Physiological characteristics

1.4.2.1 Specific characteristics of muscle fibers.

Since a swimmer’s endurance and speed depend on their ability to produce force and energy, part of the individual differences in performance can be attributed to the characteristics of the muscles of the arms and legs.

One of the muscle characteristics that has received considerable attention is the distribution of fast-twitch and slow-twitch fibers within a muscle. These include slow-twitch fibers (ST) and two types of fast-twitch fibers: FTa (fast twitch a) and FTb (fast twitch b). The nerve and the muscle fibers it stimulates together form a motor unit. In general, ST motor units are characterized by good aerobic endurance and are therefore most often recruited during low-intensity endurance activities. FTa motor units develop much greater force than ST motor units, although they fatigue much more quickly (Maglisho, 1982, p. 246).

However, it is not the contraction speed that determines the recruitment sequence of muscle fibers; rather, it is the level of force required that leads nerve cells to selectively activate ST or FT fibers. During slow, low-intensity swimming exercise, most of the force is generated by ST fibers. When the load increases and greater muscular tension is required, FTa fibers are added to the force production. In sprint distances (50 to 200 m), which require maximal force, FTb fibers are also recruited.

This suggests that all training performed at slow speed or with moderate force will favor the use of ST fibers and will, on the contrary, have little effect on FTa and FTb fibers. Thus, long training sessions at low speed do not prepare the muscle for the demands of competition, where maximal force is required from both ST and FT fibers.

Knowledge of muscle fiber composition and utilization suggests that athletes with a high percentage of slow fibers would benefit from specializing in long-distance events, whereas those with a predominance of FT fibers are better suited to short, explosive efforts.

According to Costill et al. (1994, pp. 6–7), previous studies have shown that training can increase the endurance capacity of muscle, but there is little evidence regarding the possibility of transforming ST and FT fibers through training over a few months. This supports, at least in part, the genetic hypothesis, which states that the proportion of ST and FT fibers in each individual is fixed shortly after birth and changes very little over the course of life. An exception to this rule is that FTa fibers are generally described as having a higher aerobic capacity than FTb fibers. During endurance training, FTb fibers begin to acquire characteristics of FTa fibers. More recently, Cazorla (2000, pp. 130–135) proposed another classification consisting of two groups:

- **Intermediate fibers**, composed of two types: FTa and FTb.
- **Transitional fibers**: FTab and FTc, which represent a transition from one fiber type to another. This transition could call into question the generally accepted genetically determined nature of muscle composition.

As their classification indicates, FTab fibers are situated between FTa and FTb fibers and exhibit intermediate myosin ATPase activity. Depending on the type of training, these fibers may evolve toward one type or the other. Training based on high-power, short-duration exercises could orient them toward FTb fibers, whereas long-duration endurance training would orient them toward FTa fibers. FTc fibers, on the other hand, represent a transition between ST and FTa fibers and appear in high-level athletes specializing in long-duration activities.

1.4.2.2 Interactions of the various energy processes.

During exercise, the various aerobic and anaerobic energy-producing processes are activated. One or another of these pathways becomes predominant depending on both the duration and the intensity of the effort. The three energy production processes are present in all physical exercise; each system has different but complementary characteristics and supplies energy to the muscle with different power outputs and activation times (Table 2).

Table 3: Advantages and disadvantages of each energy system
(Lacoste et al., 1998, p. 61)

Energy system	Advantages	Disadvantages
Aerobic	- Uses all substrates (carbohydrates, lipids) - Efficient - Non-toxic end products - Forms the basis of recovery processes	- Limited power output - Long start-up delay (1 to 2 minutes) - Limited endurance for exercises requiring high power
Anaerobic lactic	- Higher power output than the aerobic system - Shorter start-up delay than the aerobic system	- Use of carbohydrates in this system leads to an oxygen deficit - Lactic acid must be removed after exercise - Low efficiency - Produced lactic acid limits endurance (decrease in muscle pH)
Anaerobic alactic	- No start-up delay - Very high available power	- Use of phosphocreatine reserves leads to an oxygen deficit - Extremely short duration of action (2 to 15 seconds depending on power output)

During maximal exercise, energy is supplied during the first minute mainly by anaerobic processes. After two minutes of exercise, 50% of the energy comes from the aerobic system. The contribution of this system then continues to increase over time, becoming almost exclusive after half an hour of maximal effort (Lacoste et al., 1998, p. 61).

In most competitions, swimmers rely on at least two of these energy systems for energy production; some use all three systems, as in the 100 m freestyle. For events lasting about two minutes, the work performed by the swimmer is essentially anaerobic, whereas for longer distances such as the 1500 m, about 90% of the energy comes from the aerobic system (Table 3).

Table 4: Contribution of anaerobic and aerobic processes to effort, approximate distance
(J. E. Counsilman, 1986, p. 48)

Duration	**10 s**	**60 s**	**2 min**	**4 min**	**20 min**	**120 min**
Distance	25 m	100 m	200 m	400 m	1500 m	6500 m
Anaerobic contribution	85%	60–70%	50%	30%	10%	1%
Aerobic contribution	15%	30–40%	50%	70%	90%	99%

According to Maglisho (1982), the relative contributions of energy processes depend to some extent on the following factors:

- **Race pace**: Higher speeds involve faster muscle contractions. Energy must therefore be supplied quickly, which is why the body relies on the ATP-CP reaction and anaerobic glycolysis, which are faster and provide most of the energy in short races.
- **Swimmer's oxygen consumption capacity**: A swimmer with higher oxygen consumption can oxidize more pyruvate and NADH in the mitochondria and will depend less on anaerobic glycolysis. Fatigue will be reduced because less lactic acid is produced.
- **Technical efficiency**: A swimmer with better technique can swim at a given pace with fewer movements and less effort per movement, reducing total energy demand and anaerobic contribution.

1.4.2.3 Power and capacity of energy systems

In cyclic disciplines such as swimming, performance level is largely determined by anaerobic and aerobic energy supply. These processes, which ensure the resynthesis of muscular ATP, are characterized by their power and capacity. Power is the maximum rate of energy delivery that each energy system can provide, whereas capacity is the total amount of energy that these processes can supply over a given period of time (Platonov, 1988, p. 75).

In other words, capacity is the total amount of ATP that can be produced regardless of time, whereas power is the amount that can be resynthesized within a given time interval (Fox & Mathews, 1984, pp. 16–17). From a mechanical point of view, power is the work performed per unit of time and is expressed as: Power = work / time

Work (W) is the application of a force (F) over a distance (D) and is expressed as: $W = F \times D$, While power = $F \times D / T$, generally expressed in kg·m/min or watts (Fox & Mathews, 1984, pp. 37–38).

In summary, we have retained the approximate durations and swimming distances corresponding to the power and capacity of each energy system, as proposed by M. Verger (1993) in Table 4.

Table 5: Power and Capacity of Energy Systems
(summary based on data from M. Verger, 1993, pp. 191–194)

Energy system	**Onset delay**	**Power**		**Capacity**	
		Duration	**Distance**	**Duration**	**Distance**
Anaérobie alactique	Immédiate	0 s à 7 s	Up to ~15 m	7 s à 20 s	25 à 50 m
Anaérobie lactique	15 s à 20 s	30 s à 1min	~75–100 m	1 à 2.30 min	100 à 200 m
Aérobie	2 à 3 min	2.30 min à 5-6 min	~200-400 m	+ de 5 to 6 min	500 m to several kilometers

1.4.2.3.1 Maximum Anaerobic Alactic Power

This energy flow, or amount of work per unit of time, results from the simultaneous use of the anaerobic alactic system at a very high level, combined with lower contributions from the anaerobic lactic and aerobic systems.

The determinants of maximum anaerobic alactic power include central factors, related to motor command characteristics (temporal and spatial recruitment of a large number of muscle fibers simultaneously), and peripheral factors, related to the volume of muscle mass involved.

Maximum anaerobic alactic power increases with muscle temperature and therefore with proper warm-up. It decreases, for example, during a sprint at the end of a race, in proportion to the intensity of the preceding aerobic exercise the more intense the prior effort, the less effective the sprint (Cameron et al., 1988, p. 679).

1.4.2.3.2 Maximum Anaerobic Alactic Capacity

This corresponds to the total amount of energy available from ATP and phosphocreatine (PCr) reserves. This quantity is limited, and maximum anaerobic alactic capacity can only be maintained for approximately 6 to 10 seconds, beyond which power output declines.

At submaximal anaerobic alactic capacity, this system plays a predominant role during the first 15–20 seconds of exercise for ATP resynthesis, before being relayed by anaerobic glycolysis. This system is particularly the metabolic support for power and speed activities, such as sprints (Brunet-Guedj et al., 2000, p. 25).

1.4.2.3.3 Maximum Anaerobic Lactic Power

Maximum anaerobic lactic power is evaluated through its mechanical expression during an exercise of maximal power lasting approximately 30 seconds, during which anaerobic alactic and aerobic contributions are significant. This combined power, measured after 15–20 seconds of exercise, is lower than anaerobic alactic power.

Maximum anaerobic lactic power can be sustained for about 20 seconds, supporting with anaerobic alactic metabolism maximal efforts lasting around 40 seconds. Beyond this duration, power becomes submaximal anaerobic and contributes more than half of ATP resynthesis during intense exercise up to approximately 1.5 minutes, after which aerobic metabolism becomes predominant (McArdle et al., 2001, p. 381).

1.4.2.3.4 Anaerobic Lactic Capacity

This is the maximum amount of energy available from anaerobic glycolysis. It is low in prepubescent children but develops later, particularly through training in athletes with a high proportion of fast-twitch muscle fibers who train with short intervals of 30 seconds to 1.5 minutes (Brunet-Guedj et al., 2000, p. 29).

According to G. Cazorla (2000, p. 161), the energetic capacity of lactic glycolysis depends on an individual's ability to accumulate lactate and largely covers the energy demands of high-intensity exercises lasting between 20 seconds and 3 minutes, depending on the athlete's level of specialization and training.

1.4.2.3.5 Maximum Aerobic Power

Maximum aerobic power is represented by its biological equivalent: the maximum oxygen uptake rate, defined as the maximal volume of oxygen absorbed at the pulmonary level, transported by the cardiovascular system via hemoglobin, and utilized in mitochondrial oxidative phosphorylation, particularly in muscle tissue.

This maximal oxidative rate is measured as VO_2max, or its mechanical equivalent allowing for efficiency maximum aerobic power (MAP). In field conditions, it corresponds to maximum aerobic speed (MAS). According to Desnus et al. (1990, p. 13), this power can only be maintained for a few minutes, even in highly trained athletes in energy-demanding disciplines.

Two main factors influence VO_2max:

- The capacity of tissues to utilize oxygen
- The ability of the cardiovascular system to transport oxygen to tissues

1.4.2.3.6 Maximum Aerobic Capacity and Endurance

Maximum aerobic capacity is the maximum amount of energy available from the oxidation of energy substrates. Maximum aerobic endurance, more commonly used, refers to the time to exhaustion during exercise performed at a given percentage of VO_2max or MAP.

Maximum aerobic endurance corresponds to an energy expenditure, a quantity of work performed, or a distance covered (Brunet-Guedj et al., 2000, p. 4).

For long-duration exercise, performance differences among athletes depend both on differences in VO_2max and on the percentage of VO_2max that can be sustained over a given period (Desnus et al., 1990, p. 14).

According to Cazorla (2000, p. 167), although carbohydrate and especially lipid reserves are substantial and oxygen availability is virtually unlimited, aerobic metabolic capacity is not infinite and depends on several factors:

- Exercise intensity: above 75% of VO_2max, energy relies primarily on carbohydrate stores, which limit activity duration to about 1 hour 30 minutes in untrained individuals
- The individual's level of training
- Thermoregulatory capacity
- Fatigue, particularly related to neuromuscular and joint factors

1.5 Course Objectives

The aim of this course is to provide students with a scientific and technical understanding of swimming as a physical and sporting activity, by analyzing its internal logic, environmental constraints, and performance requirements.

At the end of this course, students should be able to:

- Explain the internal logic and specific characteristics of swimming as a motor activity;
- Understand the specific constraints of the aquatic environment and their effects on motor behavior ;
- Understand the role of visual, tactile, auditory, kinesthetic, and vestibular information in motor control;
- Analyze swimming as a technical and performance-oriented activity;
- Identify the biomechanical, physiological, and perceptual determinants of swimming performance;
- Explain the process of adaptation to the aquatic environment, particularly in terms of balance, propulsion, breathing, and information intake;
- Distinguish between exteroceptive and proprioceptive sources of information in swimming;
- Interpret performance demands according to swimming strokes, distances, and training conditions;
- Understand the factors determining swimming performance, integrating morphology, physiology, energy systems, and psychological aspects to optimize training and competition results ;
- Apply theoretical knowledge to the analysis of swimming techniques and training situations;
- Develop a scientific approach to swimmer development and long-term training planning.

1.6 Evaluation

Student assessment is based on continuous evaluation and final examination, combining theoretical knowledge and applied understanding.

Evaluation methods may include:

- **Written examination** (theoretical concepts, definitions, analysis of swimming situations);
- **Coursework or assignments** (technical analysis of swimming strokes, performance factors, or adaptation processes);
- **Oral presentation** (analysis of a scientific article or a technical swimming topic);
- **Class participation** (discussion, analysis, and critical reflection).

Evaluation criteria focus on:

- Accuracy and clarity of scientific concepts;
- Ability to analyze swimming-specific situations;
- Appropriate use of technical and scientific terminology;
- Coherence and structure of written and oral responses.

Sample exam questions:

1. Explain the impact of body surface area and limb length on sprint versus distance swimming.
2. Describe recruitment of muscle fiber types during a 50 m versus 1500 m race.
3. Compare the contributions of anaerobic alactic, anaerobic lactate, and aerobic systems in a 200 m freestyle event.

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Chapter 2: Biomechanical Bases

Introduction

In this course, we will address the biomechanical principles related to swimming to better understand the forces acting on a swimmer and the hydrodynamic laws governing their movement, considering the specific characteristics and constraints of the aquatic environment.

The forward movement of a swimmer results from several forces, the first of which is propulsion (locomotor actions that interact with resistance to gain leverage on the water). Particular attention will be given to the various theories and models of propulsion. The second force is resistance to motion (opposing reactions that act against forward movement), and we will present its different types. A third force, related to body positioning as well as propulsive or non-propulsive segments, is lift, which indirectly affects the other two forces. These factors have fundamentally different roles depending on whether the biomechanical principles are associated with Newton’s Third Law or Bernoulli’s principle.

The importance of this course is clear: to improve, a swimmer must reduce negative resistances while increasing resistances that act in the direction of movement. To achieve optimal swimming efficiency, the swimmer must constantly seek a favorable penetration and forward profile adapted to hydrodynamic laws. Simply turning the arms faster will not make a swimmer go faster.

2.1. Buoyancy

2.1.1 Definition of Buoyancy

Buoyancy is a form of static equilibrium in water, in which part of the body is submerged while another part is above water. In humans, this equilibrium is vertical. The emerged part is generally limited to some portion of the head, while most of the body volume remains submerged (Chollet, 1997, p. 22).

In water, humans are not in their natural element and encounter difficulties adapting. Their buoyancy, as well as their ability to maintain a horizontal position, affects swimming technique and performance (Pedrolletti, 2000, p. 15).

2.1.2 Forces Acting on a Swimmer

At the water surface, a person is subjected to gravity, which acts downward, and to Archimedes’ buoyant force, which pushes upward (Boullé-Giammatteï, 2010, p. 20).

A body in water is influenced by several forces:

- Weight (gravity): a vertical downward force applied at the center of gravity. On a solid surface, a body is balanced when the center of gravity projects within the base of support.
- Buoyant force (Archimedes’ principle): any body immersed in a fluid experiences an upward force equal to the weight of the displaced fluid, applied at the geometric center of the displaced volume (center of buoyancy) (Chollet, 1997, p. 22).

2.1.3 Swimmer’s Buoyancy

Human buoyancy depends on the relative densities of the water and the body. One floats better in saltwater (density ≈ 1.025 at 15°C) than in freshwater (≈ 0.997 at 25°C).

Human body density is the ratio of weight to volume. Heavier bones and muscles, or lower lung capacity, reduce buoyancy. Most people float during forced inspiration, but anthropometric characteristics affect how well they float (Pelayo & al., 2000, p. 229).

If gravity exceeds Archimedes’ force, the body sinks; if the opposite, it stays at the surface. Some people struggle to float in freshwater due to high body density, low fat, or high bone density. Lung inflation has a major effect on buoyancy; low buoyancy makes learning to swim more difficult (Grimshaw & Burden, 2010, pp. 278-279).

Because humans have heavy skeletons and muscles, their body density exceeds water, requiring strategies to stay afloat: lung inflation, pressing down on water, or active swimming to counter excess weight.

Without movement, the simplest way to change body density is to inflate or deflate the lungs. If density exceeds water (lungs empty), we sink; if lower (lungs filled), we float.

Water is favorable for movement: apparent weight is null (with positive buoyancy), so the swimmer only opposes forward resistance. Water is ~800 times denser than air, but with a streamlined, floating body, swimming is more energy-efficient per kg per distance than moving on land (Boullé-Giammatteï, 2010, p. 20).

Buoyancy depends on bone mass (density 1.8 N/dm^3), muscle mass (1.05), and fat (0.95). Women (23% body fat) float better than men (15%) (Pelayo et al., 2000, p. 229; Leblanc et al., 2010, p. 153).

Chollet (1997, pp. 23-24) notes that body volume can be measured by displaced water volume. Simple methods involve water level measurements before and after immersion.

Three main techniques assess buoyancy during inspiration:

1. Measure underwater weight of the submerged subject.
2. Add weight to a floating, compact body until full submersion.
3. Anatomical marker method: subject maintains vertical static balance, arms along the body, head horizontal. Water level indicates buoyancy: low (up to forehead), medium (eyes), good (chin) (Cazorla, 1993, p. 101).

Individual differences are large, influenced by age and sex. All buoyancy tests are done in forced inspiration; in expiration, all humans sink.

2.2. Aquatic Balance

2.2.1 Swimming Balance

According to Didier Chollet, aquatic balance corresponds to a state of rest of the human body subjected to gravitational forces that are balanced by buoyant forces (Archimedes' thrust). This state of rest highlights the static nature of balance (Chollet, 1997, p. 26).

Swimming balance requires the body to be in a horizontal position.

- **Buoyancy** in humans corresponds to a static vertical balance.
- **Aquatic balance** corresponds to a static horizontal position.
- **Aquatic equilibration** corresponds to a dynamic horizontal state.

With regard to balance, three types can be distinguished:

- **Stable balance**: the system remains in the position in which it is released;
- **Unstable balance**: the body position changes in order to reach a stable equilibrium;
- **Neutral (indifferent) balance**: regardless of the initial orientation of the body, this orientation is maintained (Chollet, 1997, p. 26).

2.2.2 The Righting Moment

The legs are relatively heavy and have a smaller volume compared to the lungs, which are much lighter and larger in volume.

- The swimmer's center of gravity is therefore located closer to the legs,
- while the center of buoyancy (center of volume) is located higher, around the abdomen or lower chest;
- the center of gravity is generally situated at the level of the pelvis;
- the center of buoyancy is situated higher, toward the abdomen or lower chest.

As a result, the centers of gravity and buoyancy do not coincide; they are located at different vertical levels.

Consequently, the legs tend to sink while the chest tends to float. When lying at the surface of the water, the body is in an unstable equilibrium.

Two opposing forces gravity and buoyant force act on the body at different points of application. This creates a righting moment, which tends to restore the body to a stable equilibrium by aligning the points of application of gravitational force and buoyant force along the same vertical axis.

During swimming, in a dynamic context, the arms when extended forward:

- play an important role in bringing the points of application of gravity and buoyancy closer together;

- thereby facilitate a more stable horizontal body position in the water (Pedroletti, 2009, pp. 64–65).

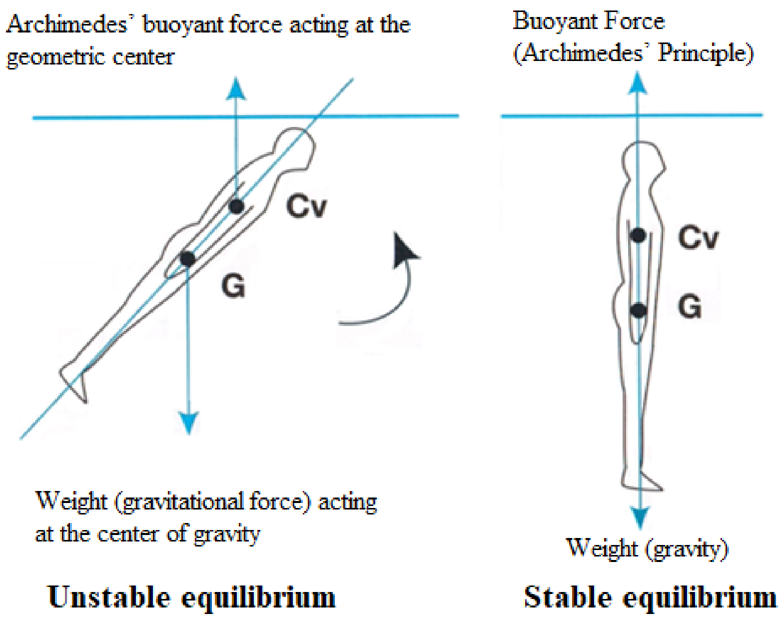


Figure 2: Righting Moment (Pedroletti, 2009, p. 65)

2.2.3 Swimmer's Balance Level

A static balance test can be implemented with swimmers. It consists of evaluating the time interval between the moment when the subject is in a horizontal static balance and the moment when they reach a vertical balance. The longer this time interval, the better the swimmer's horizontal balance.

It can be observed that the initial phase of imbalance is the longest; once the righting process is initiated, the return to vertical position occurs more rapidly when the head is in a raised position or when the body is already initially inclined.

It is important to clearly emphasize that the search for horizontal balance is a necessity for any individual who wishes to swim efficiently, insofar as this position is the only equilibrium position that limits resistance to forward motion during displacement. However, this horizontal balance must be constructed, as it results from specific voluntary actions (Clarys & Jiskoot, 1978, p. 71).

2.2.4 Head Positioning and Aquatic Balance

Head position can also have a significant influence on maintaining good horizontal stability. One of the first actions required to achieve horizontal balance is tilting the head in order to align the body segments horizontally. This tilting action also helps manage the emerged body volume so that it is distributed as centrally as possible relative to the entire body. Conversely, raising the head accelerates the process of vertical righting.

In the case of prone balance, this head tilting has consequences for breathing, as the airways then become submerged. The issue of sustained static balance can only be resolved through a dorsal balance position commonly referred to as *“the float”* which allows the airways to remain above the water surface.

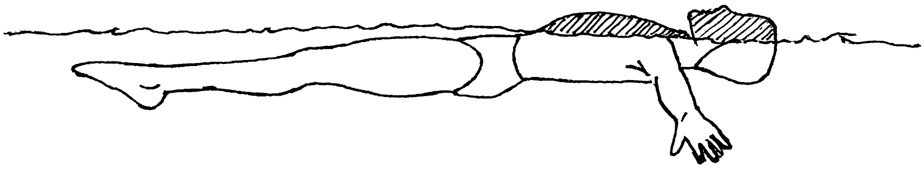


Figure 3: Dorsal Balance

The head is nevertheless maintained in horizontal alignment; the occipital region is clearly submerged, and the external ears are underwater. In the case of dorsal balance, another source of imbalance may occur: lateral rotation. To avoid or reduce this, the appropriate arm position is lateral abduction, with the arms spread outward (Chollet, 1997, pp. 28–29).

2.3 Swimmer’s Equilibration

2.3.1 Concept of Equilibration

Any movement or displacement represents a transient state of imbalance that must be continuously restored. Bipedal posture requires maintaining balance under static or dynamic conditions across highly variable support situations.

In posturology, the term *“static balance”* is often used despite its mechanical inaccuracy. This terminology is commonly employed in the literature to distinguish situations in which the body is voluntarily moving from those in which it is subjected to external perturbations. When a body is in motion, it is therefore in a state of transient imbalance. This is referred to as *dynamic balance.* Human equilibration is thus a process of continuous balance restoration (Paillard, 2016, p. 1).

Unlike balance, which is a concept with a static character, equilibration is inherently a dynamic notion. According to Gribenski (1980, cited by D. Chollet), *“It is the function by which humans maintain their balance at all times.”* This dynamic concept may therefore aim at the recovery of a disrupted balance and thus represents an active re-equilibration function.

Because the aquatic environment is a specific medium without fixed support points and due to the deformable nature of the human body, the equilibration function becomes essential. Consequently, when swimming, individuals are constantly recovering from imbalances (Chollet, 1997, p. 32).

The practice of physical and sporting activities modifies the sensorimotor strategies involved in the equilibration function; however, these modifications differ according to the specific demands of each sport.

2.3.2 Relationship Between Equilibration and Breathing

One of the first static imbalances is related to inhalation. The duration of ventral balance depends on the subject's respiratory capacity. When the head is submerged, inhalation is temporarily prevented. The inspiratory phase, which involves lifting the head, disrupts body alignment and horizontal positioning.

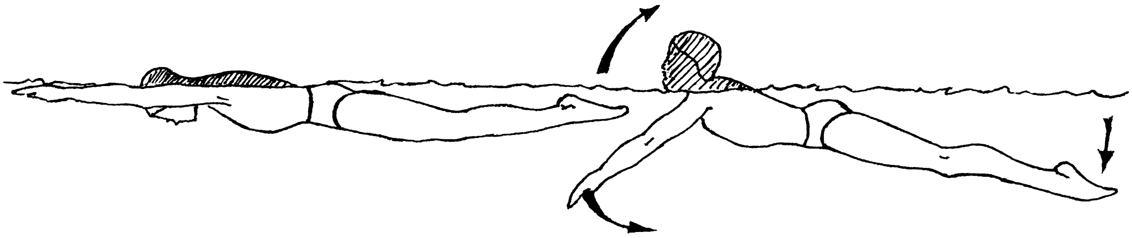


Figure No. 4: Righting movements related to information intake

Each inhalation must therefore be followed by an active movement of head flexion that restores the balance temporarily disrupted, while seeking to correctly reposition the body segments mobilized during this respiratory phase.

Moreover, breathing except in the case of backstroke, where the airways are above water constitutes a major disturbing factor of balance. A contradiction thus appears: the more one breathes, the more swimming balance is disrupted due to changes in head position; but the more effectively one breathes, the more oxygen is supplied to the muscles involved in the action, allowing them to function at maximum efficiency. This shows that breathing should not be left to chance but organized according to a certain number of factors. The number of inhalations over a distance must be optimal; that is, it must allow a sufficient oxygen supply while disturbing the body as little as possible. This implies the effectiveness of each breathing cycle, in which inhalation must be as complete as possible.

One aspect highlighting the importance of reducing inhalation time is directly related to balance: to create the least disturbance, inhalation should be very brief. This action aims to limit, in time, the reduction of buoyant force (Archimedes' thrust) and the dynamic imbalance caused by lifting part or all of the head out of the water. Furthermore, the moment chosen to perform this inhalation should not be left to chance; it should occur at the end of a propulsive path, regardless of the swimming stroke (Chollet et al., 1997, p. 170).

2.3.3 Relationship between balance control and information intake

Information intake in the aquatic environment is quite specific compared to usual actions. Due to the immersion of the eyes in water, the quality of visual information intake is reduced (or even completely eliminated in the case of beginners who close their eyes), insofar as the eye is in direct contact with water, allowing only blurred visual perceptions. The swimmer must therefore rely on indirect cues (for example, a swimmer moving forward looks downward at a 90-degree angle to observe the lines on the bottom of the pool, designed to inform them of their position within the pool space).

What organizes the swimmer is the informational function, with a constant search for visual references, which may conflict with maintaining the “shoulders–head” block and head immersion. At this stage, the teacher should not focus on what the swimmer sees; instead, swimmers often display disorganized breathing, favoring long apnea phases interrupted by expiration and inspiration performed with the face completely out of the water. The problem is not respiratory in nature; it is postural and informational (Arieu & Dupouy, 2008, p. 28).

This visual information intake nevertheless poses several problems related to balance control: it is particularly observed among beginner swimmers, but also at the subsequent stage, that lifting the head out of the water—thus disturbing balance is not due solely to inhalation, but also, and in some cases primarily, to the act of seeking visual information. This information intake then becomes another source of imbalance.

2.3.4 Relationship between balance control and propulsion

Another rebalancing action is associated with both the destabilizing and rebalancing consequences of body displacement in the aquatic environment. Experience shows that a flag falling without wind collapses, but remains upright when wind blows. The same occurs when the flag is moved at high speed even without wind.

When stationary, a swimmer’s feet tend to sink. Conversely, when the swimmer is pulled forward, they experience water resistance that tends to lift the lower limbs. This forward propulsion may result from external traction (e.g., a pole pulled from the poolside by a lifeguard), but it can also be generated by propulsive actions of the upper limbs. Additionally, the speed of the body that raises the lower limbs may result from a dive or a push-off from the wall forward; this is known as the prone glide, an action in which balance is facilitated by an active contribution of the water (Chollet, 1997, pp. 30–34).

2.3.5 Balance control and resistance to forward motion

Rebalancing mechanisms are also closely linked to reducing resistance to forward motion. A balanced body using supports in the water moves in the opposite direction of its supports: if it pushes downward, it tends to rise relative to the water level; however, buoyant force then decreases since part of the body emerges from the water, which significantly limits this action. In the case of a backward push, the body advances, and the limitation will depend on the force exerted relative to the body’s resistance to forward motion.

A very important link appears between balance and displacement: to move at the same speed, an individual with better balance will expend less energy than another; they will therefore be able to swim longer, and if they have the same propulsion, better balance will allow them to swim faster. To increase speed, a swimmer may choose to reduce resistance to forward motion, increase effective propulsion, or use a combination of both factors (Schleihauf, 1974, p. 94).

Thus, it appears that in front crawl, the lower limbs play an essential role in balance control. At high swimming speeds, it has been demonstrated that the leg kick has little or no propulsive effect; instead, swimmers use leg actions to restore balance in the three planes of space. First, to raise the feet toward the surface (reduction of pitch). Second, to prevent lateral oscillations caused by alternating arm movements (reduction of yaw). Third, to reduce longitudinal roll linked to the immersion of one propulsive arm and the aerial recovery of the other.

These examples clearly show that physical laws and their practical consequences are not the same in static and dynamic conditions, and that numerous paradoxes complicate the analysis of swimming activity.

If swimming is considered a complex task, it can be subdivided into subtasks: balancing, organizing oneself in relation to encountered resistances, ensuring respiratory exchanges, gathering information to orient and move, and thus to propel oneself. The traditional notion of swimmer balance is most often represented by a particular moment in the synchronization of limb motor actions and is expressed by a general body extension in an orientation close to horizontal. In reality, the problem of balance is more complex and integrates data from statics and dynamics, conscious and unconscious aspects, and opposing mechanisms (Catteau & Garoff, 1986, p. 65).

The reference posture must be streamlined, toned, and aligned. This allows the swimmer to reduce resistance to forward motion, achieve economical swimming, and perceive the first sensations associated with moving through a fluid medium. In this posture, following head tilt, vision is oriented vertically. This modification of visual information requires the swimmer to reconstruct spatial orientation based on indirect reading of pool-bottom markers and new tactile and proprioceptive cues (Arieu & Dupouy, 2008, p. 28).

Study shows that body balance is hierarchically and chronologically the first motor problem to be solved. However, from the perspective of effective aquatic movement, it cannot remain isolated for long from the other factors of swimming (Chollet, 1997, p. 36).

2.4 Resistance to Forward Motion

2.4.1 Differentiation between resistance to forward motion and propulsive resistance

Mechanical and biomechanical concepts and notions have evolved over time thanks to advances in scientific knowledge. According to Chollet (1997, p. 48), resistance to forward motion should not be confused with propulsive resistance. Lift forces are fundamentally different from drag forces. It is also necessary to distinguish between wave resistance, friction resistance, and eddy (wake) resistance, just as it is important to differentiate between form drag, wave drag, and friction drag.

Drag is a force generated by the relative motion of a body in a fluid. This force is directed opposite to the body's displacement and is referred to as hydrodynamic resistance when the fluid is water. Drag depends on the drag coefficient (representing the streamlining of the body), the density of the fluid, the area of the body's cross-section, and the square of the velocity (Grimshaw & Burden, 2010, p. 276).A swimmer in motion is a system that creates zones of resistance, which tend to slow down their action. The forward progression of the swimmer's body results from several forces:

- **Propulsion**: locomotor actions that seek resistance in order to establish supports against the water.
- **Resistance to forward motion**: braking reactions that occur on all areas moving more slowly than the propulsive supports.

- **Lift**: related to body positioning as well as to propulsive or non-propulsive segments. Lift has indirect implications for the other two forces.

The laws of fluid mechanics governing resistance are the same whether the body moves through a volume of still water or remains stationary in a moving water current under identical speed conditions. This form of resistance (in both cases) is referred to as passive resistance; it can be measured, for example, by towing an immobile swimmer through the water. Active resistance, on the other hand, corresponds to that experienced by a swimmer during actual swimming, that is, while performing propulsive motor actions (Chollet, 1997, pp. 48–49).

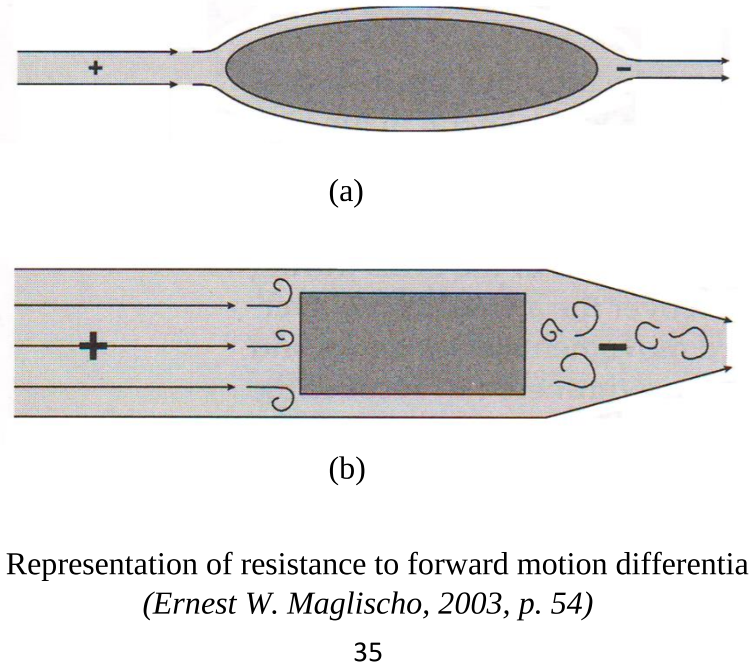
According to Costill et al. (1994, p. 43), water offers resistance to the swimmer's movement. To reduce this resistance as much as possible, swimmers should seek the most elongated position possible. The continuity of motor actions and aerial recoveries makes front crawl the fastest stroke. In breaststroke, resistance to forward motion is high due to underwater recoveries and the discontinuous nature of propulsion. The reduction of resistance to forward motion is not the same for beginners and expert swimmers. Beginners tend to adopt an oblique position in the water and aim to reduce resistance by seeking horizontal balance without prioritizing speed. Expert swimmers, already in horizontal balance, aim to reduce braking resistance while increasing swimming speed.

2.4.2 The different types of resistance to forward motion in water

A swimmer in motion is subjected to three forms of resistance in water:

2.4.2.1 Form resistance or form drag

A streamlined shape produces the least drag in water. The two objects represented in this figure have exactly the same maximum cross-sectional area but do not have the same shape; therefore, they do not offer the same resistance to forward motion. In Figure No. 5, object (a) has a suitable shape for moving through water: it is streamlined at both ends. In contrast, the shape of object (b) is unsuitable, as it has too many squared edges that interrupt the flow of water toward the rear (Maglischo, 2003, p. 54).



(a)

(b)

Figure No. 5: Representation of resistance to forward motion differentiated by shape *(Ernest W. Maglischo, 2003, p. 54)*

Form drag is the resistance that results from the shape of an object moving through water. Reducing the frontal area opposing the movement of water makes it possible to decrease this type of resistance. Therefore, the body should always be kept as close as possible to a horizontal balance, maintained in an elongated and aligned position, and unnecessary movements should be eliminated (Hines, 2000, p. 30).

Unfortunately, swimmers' bodies cannot remain in a static position while swimming. They constantly change position and present a wide variety of orientations to the water they move through. Compared with slower swimmers, faster swimmers maintain the most streamlined shape possible while changing position (Costill et al., 1994, pp. 44 - 45).

Form resistance therefore depends on the shape of the swimmer's body as it moves through the water and corresponds to resistance to forward motion linked to vertical or lateral movements, which increase the frontal surface area (frontal resistance, thus related to the maximum cross-sectional area and body shape), as well as the posterior surfaces that negatively affect suction (wake drag or posterior vortex drag, also known as tail suction) (Chollet, 1997, p. 53).

Moreover, a glide with the arms extended in line with the body allows a greater distance to be covered than a glide with the arms along the thighs. Indeed, body length also influences resistance to forward motion: the more elongated a body is, the lower the resistance. Ungerechts and Niklas (1994) show that at the same speed, passive resistance decreases progressively as the object becomes more elongated.

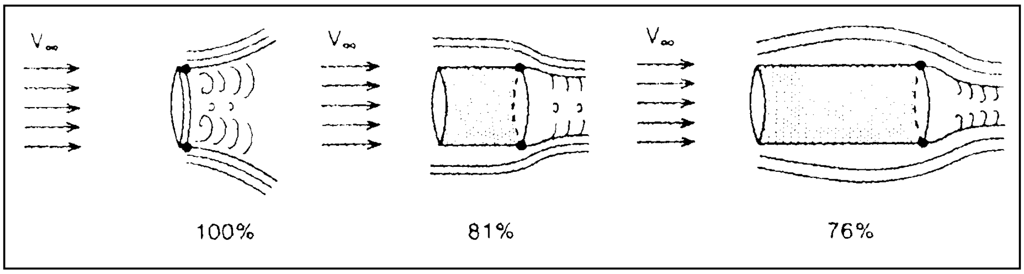
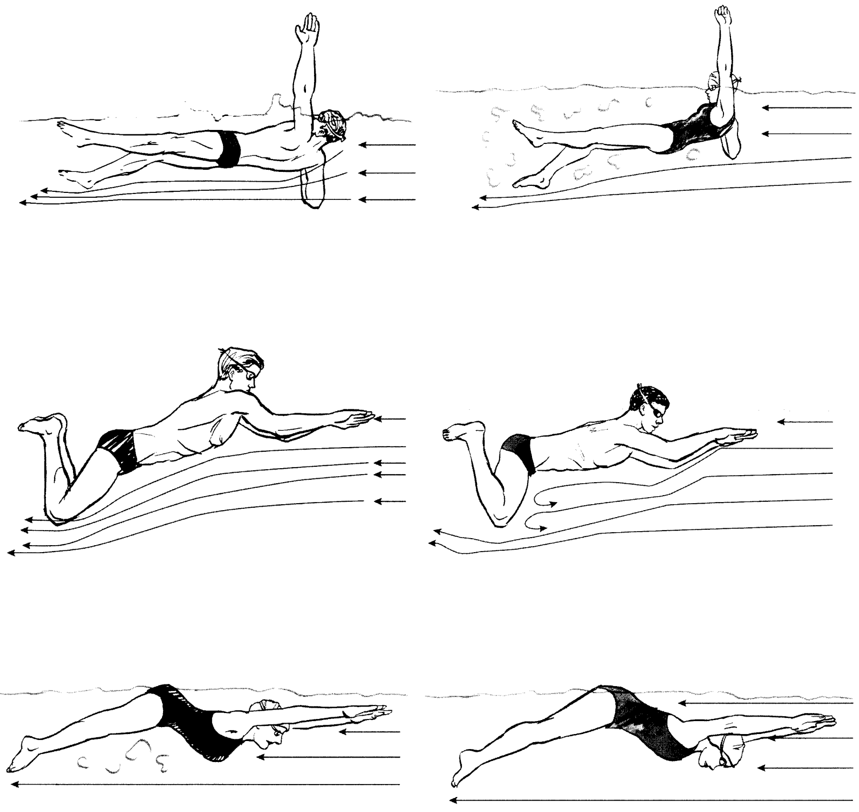


Figure No. 6: Reduction of passive resistance as the length of a solid increases, for the same maximum cross-sectional area and at the same speed
(Ungerechts & Niklas, 1994, p. 138)

Thus, the swimmer seeks to minimize the space they occupy by remaining as horizontal as possible. The body must be oriented so that all its contours progressively taper toward the rear, while presenting the smallest possible surface area to the water in front. The swimmer must find a compromise when striking the water with the feet: deep enough to propel the body forward, but not so deep as to increase form drag beyond what is strictly necessary. The body should not twist excessively from side to side. Finally, the swimmer must be aware of maintaining good horizontal alignment in all swimming strokes, and good lateral alignment in front crawl and backstroke (Costill et al., 1994, p. 46).

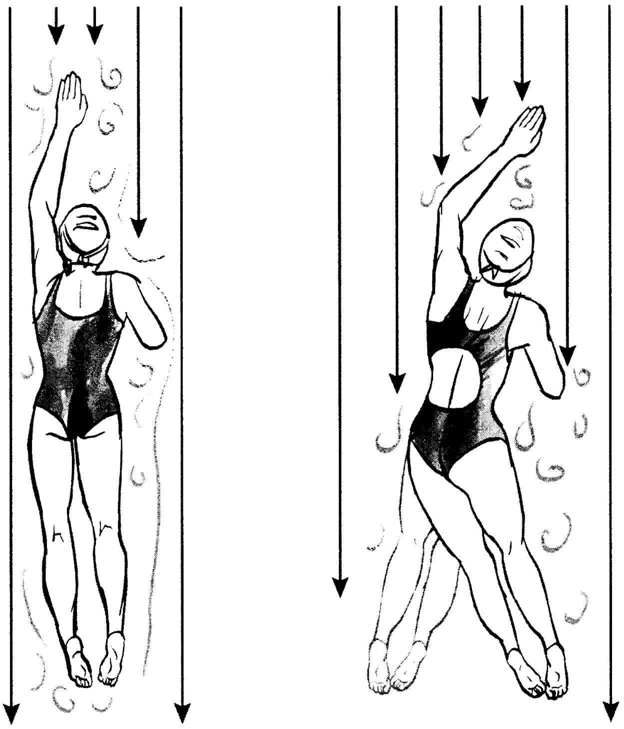
The following diagrams highlight the differences between good and poor horizontal alignment in three of the four swimming techniques (Figure No. 7).



(a) Good body alignment (b) Poor body alignment

Figure No. 7: Comparison between good and poor body positions in three of the four swimming strokes *(Ernest W. Maglischo, 2003, p. 52)*

Moreover, excessive side-to-side body movements can disrupt lateral alignment in the front crawl and backstroke techniques. Figure No. 8 shows a top view of front crawl swimmers. The swimmer on the left is well streamlined, whereas the swimmer on the right twists excessively from side to side. This swimmer inserts her hand into the water across the body’s midline, which causes an outward movement of the hip behind the arm and a lateral movement of the legs in the opposite direction. These lateral swinging movements increase turbulence around the body (Costill et al., 1994, pp. 46–48).



(a) (b)

Figure No. 8: Effects of good and poor lateral alignment in front crawl
(Ernest W. Maglischo, 2003, p. 53)

2.4.2.2 Wave resistance or wave drag

The body fights wave drag by creating a wake, just like boats do. To move forward at the surface, it must push water out of its path by forming a wave. The creation of this wave requires energy, all of which is supplied by the swimmer, and the amount depends largely on the distance the water must travel to move away from the path described by the body. The wider the path the swimmer opens at the surface, the larger the wave and the greater the energy expenditure required to overcome wave drag (Hines, 2000, pp. 30–31).

When a body moves at the surface of a liquid, a turbulent zone is created, producing waves, the most significant of which are the bow wave at the front of the body and the stern wave at the rear. Like all forms of resistance, wave drag depends among other factors on the swimmer's speed and body shape, and it is directly linked to movements performed near the water surface.

Waves and water turbulence create a high-pressure zone that acts as a major brake on the swimmer's forward motion. Some external waves affecting the swimmer can be reduced through the use of "anti-wave lanes," but it is mainly the waves caused by poor body positioning or poor water entry that limit propulsive efficiency. The movements that contribute most to wave creation are vertical movements upward and downward especially when they occur close to the water surface. These most often correspond to the phases of water entry and exit of the propulsive segments (Chollet, 1997, p. 55).

These movements create arcing waves that press against the swimmer's body and slow their speed. Such arcing waves are generated by the swimmer's head and trunk when they move forward, sideways, or upward and downward. They are also produced by the recovery movements of the arms and legs. The limbs push forward against the water, creating turbulence that increases pressure at the front of the body and secondarily produces a backward-directed force that rapidly and significantly slows the swimmer's speed (Costill et al., 1994, p. 48).

2.4.2.3 Friction resistance or skin drag

Friction drag is caused by the friction of a body moving through water. This type of resistance cannot be reduced through technique, but rather through preparation and equipment. Properly fitted swimsuits and swim caps help achieve this goal. Friction drag can also be reduced by wearing competition swimsuits made from advanced technological materials designed to limit water absorption (Hines, 2000, p. 31).

When a body moves through a fluid, the fluid molecules closest to the body adhere to it. As these molecules move away from the body surface, their velocity changes and, beyond a certain distance, matches the velocity of the fluid in the outer flow around the body. The thin layer of fluid in which this velocity gradient occurs is called the boundary layer. Because these adjacent layers of fluid have different velocities, significant viscous forces are generated (Chollet, 1997, p. 55).

According to Costill et al. (1994, pp. 43-49), the main factors influencing the magnitude of friction drag experienced by swimmers are their frictional surface area, their speed, and the roughness of their body surface. Swimmers cannot influence their body surface area, and they can only affect their speed by choosing the appropriate pace in the early part of the race. This means that the only significant way to reduce friction drag is to smooth the friction surface. Smooth surfaces clearly generate less friction than rough surfaces, which explains why some swimmers shave before major competitions.

Drag resistance is linked to changes in water flow around the swimmer. Flow can be either laminar or turbulent. In laminar flow, water molecules move in linear, homogeneous streams. This type of flow produces little resistance, as water molecules slide smoothly along the flow layers without disturbance. When these laminar flows encounter an obstacle, such as a swimmer's body, the molecules are redistributed unevenly in all directions, and the flow becomes turbulent.

The molecules bounce in all directions, collide with nearby flow lines, making them turbulent as well, and so on. In front of the body, this expanding turbulence creates a high-pressure zone that slows the swimmer. Because the flow lines are completely disrupted, no laminar flow can occur around the immersed body. These flow lines only rejoin far behind the swimmer. A low-pressure vortex zone forms at the rear, creating a suction effect that also slows forward progression. These effects can be observed through the air bubbles underwater that surround the swimmer's segments. Turbulent flow creates vortex currents that hinder the swimmer.

The phenomenon of low pressure and suction behind the body is effectively used in training when a swimmer positions themselves in the wake of another swimmer's kick to benefit from reduced resistance and suction effects.

Thus, the more or less streamlined shape of a body immersed in a fluid is of great importance. Unfortunately, the swimmer's body is not naturally adapted to the aquatic environment. Careful attention must therefore be paid to body position in order to minimize the disadvantages caused by turbulent flow of the various streamlines and by differences between frontal and rear pressure zones.

2.5 Swimmer Propulsion

The swimmer is confronted with a double imperative:

to reduce the resistances to forward motion that oppose displacement, and to increase the propulsive resistances created by the limbs in order to move faster. The swimmer's displacement is therefore conditioned by the creation and maintenance of these propulsive resistances.

Thus, in one case, resistances are the consequence of the action of water on the body and are passively endured by the swimmer. In the other case, the swimmer actively creates these resistances. From a theoretical point of view, these propulsive resistances can be generated according to different biomechanical models with highly variable efficiencies (Toussaint & Beek, 1992, p. 9).

According to Maglischo (2003, pp. 5–12), many theories exist on this subject, but none of them has been definitively proven. Many experts accept Bernoulli's theorem as the basis of propulsion in swimming. Even though it is certainly the most commonly accepted theory today, it is probably not the main physical law that swimmers use to propel their bodies forward. The primary propulsive mechanism used by swimmers is more likely based on Newton's third law.

According to the same author, the main reason Newton's action–reaction law was rejected in favor of Bernoulli's theorem was probably the study by Brown and Counsilman (1971). They showed that swimmers propel themselves more through diagonal movements than through movements directed straight backward, which led researchers to seek another explanation for propulsion in swimming. Unfortunately, Newton's law was misinterpreted by assuming that swimmers had to push directly backward with their arms and legs to push water backward. It was not realized that swimmers can push water backward very effectively even when propelling in diagonal directions.

Swimming displacement is the result of the propulsive action of the legs and arms in the water. The efficiency of displacement depends on the relationship between hydrodynamic laws (Newton's laws and Bernoulli's principle) and the coordination of motor actions (Tourny et al., 1994, p. 43).

For their part, Sprigings and Koehler believe that, from a practical point of view, the predictive potential of a model based on Newton's laws is superior to that of a model based on Bernoulli's theorem. The main characteristics of lift and drag can be derived using an approximate method based on the application of Newton's second and third laws rather than Bernoulli's equation. The advantages of the Newtonian model, compared with the Bernoulli model, are that it can be used to provide both quantitative and qualitative data and that it is intuitively easier to understand, making it possible to derive relatively simple and reasonable equations (Sprigings & Koehler, 1990, p. 244).

2.5.1 Main Theories of Propulsion

2.5.1.1 Propulsion model based on Newton's third law (action/reaction)

This model is based on the law linking action and reaction, which can be expressed as follows: when swimmers push water backward, they accelerate forward with a force of equal magnitude. In other words, for every action there is an equal and opposite reaction. Consequently, if a swimmer wants to move in a given direction, they must exert a force with their limbs in the opposite direction. For the swimmer, this results in orienting the propulsive surfaces (for example, the hand) perpendicular to the direction of displacement, with the direction of the propulsive forces parallel to the direction of movement (Costill et al., 1994, p. 50).

This search for propulsive action must take into account the specificity of the aquatic environment, namely that water molecules are evasive and that any movement performed perpendicular to the direction of displacement must be carried out with progressive acceleration. This acceleration makes it possible to carry along and push against the same mass of water throughout the entire propulsive path. If the movement is not accelerated but uniform, water molecules will escape behind the hand and propulsion will be very weak or even nonexistent (Arellano et al., 2006, p. 15).

Thus, this model is based on two principles:

- Orientation of the propulsive surfaces perpendicular to the direction of displacement, with the direction of the propulsive forces parallel to the direction of movement;
- Support on a mass of water and progressive acceleration of this support in order to retain this mass of water throughout the entire propulsive movement.

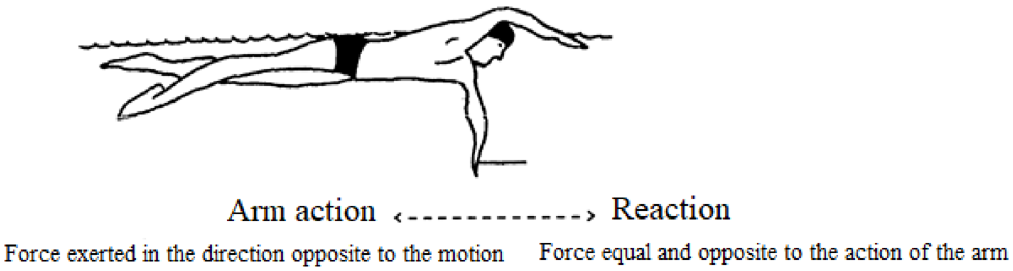


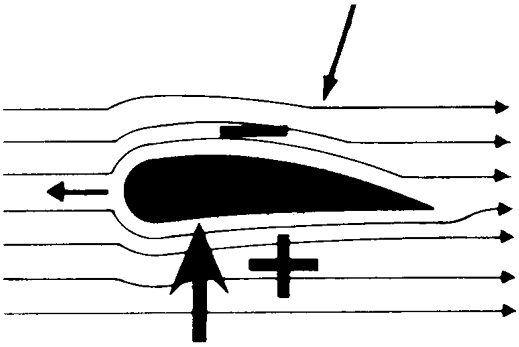
Figure 9: Application of Newton's Third Law

2.5.1.2 Propulsion Model Based on Bernoulli's Principle

For many years, it was believed that the freestyle swimmer had to pull and then push their hand along a straight trajectory underwater passing beneath the swimmer's center of gravity. This assumption was based on the idea that the swimmer used their hand like an oar, creating a wake behind it. Consequently, applying Newton's third law of action and reaction, if the swimmer wanted to move straight forward, they had to push the water directly backward.

However, underwater footage of elite swimmers demonstrated that their hands followed an S-shaped path, an inverted question mark, or other similar trajectories. Never was a champion observed moving their hand in a straight line (Counsilman, 1986, p. 179).

Bernoulli's principle states that the pressure of a fluid is related to the increase in its flow velocity. For example, airplane wings are designed to be inclined relative to the direction of motion so that air flows much faster over the upper surface of the wing than the lower surface. This difference in airflow velocity results in increased pressure below the wing and decreased pressure above it. The result is lift, or in other words, an upward force acting against the wing (Figure 10).



Water flows faster here, causing a decrease in pressure

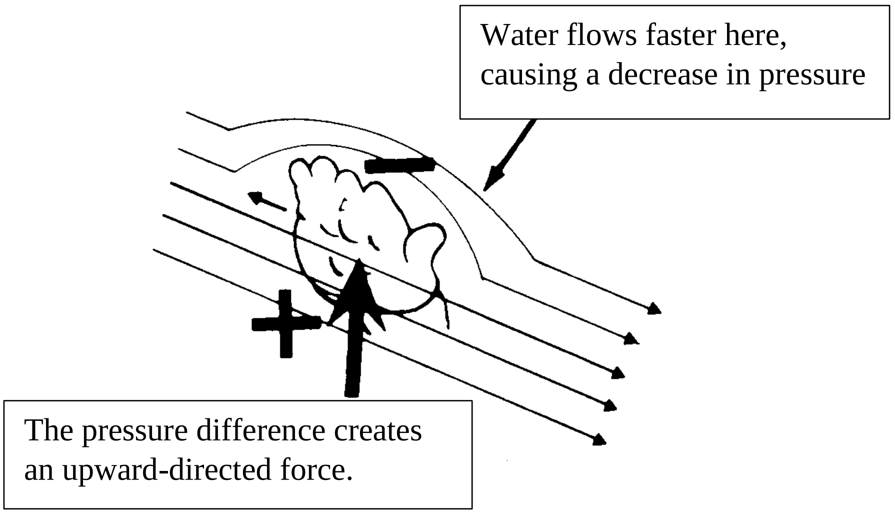
The pressure difference creates an upward-directed force.

Figure 10: Application of Bernoulli's principle on an airplane wing (J.E. Counsilman, 1986, p. 180)

The basis of propulsion, according to Bernoulli's theorem, is that swimmers use their hands like wings. When water flows over them, it moves faster on the dorsal side than underneath on the palmar side. This creates a pressure difference between the palmar and dorsal surfaces, producing a lift force. When this lift combines with the drag force acting on the hand, it generates a resultant force that propels the swimmer's body forward (Toussaint & Beek, 1992, p. 12).

Although it is highly likely that lift and resultant forces are indeed produced when the swimmer pushes diagonally, the magnitude of these forces is probably more related to the swimmer's hand attack angle and the backward displacement of water it generates than to any acceleration of the fluid flow above their dorsal joints. If this were not true, swimmers would not need to orient their hands at different angles while moving; they could simply use their hand like a wing to produce these forces in accordance with Bernoulli's theorem. However, research and individual observations have shown that swimmers generate more force when moving their hands in water using very precise attack angles (Costill et al., 1994, pp. 50-51).

A boat propeller works in a similar way, providing a forward-directed propulsive force. Likewise, a swimmer's hand, if properly angled relative to its trajectory in the water, can act like an airplane wing or a boat propeller, enabling forward propulsion of the swimmer (Figure 11)


Water flows faster here, causing a decrease in pressure

The pressure difference creates an upward-directed force.

.Figure 11: Application of Bernoulli’s principle on the swimmer’s hand (J.E. Counsilman, 1986, p. 180)

2.5.1.3 Forces Exerted by a Fluid on a Profile

If we consider a fixed obstacle (the swimmer’s hand or an airplane wing) and a fluid moving at a constant speed, the resultant force exerted on the swimmer’s hand or the wing can be reduced to a single force: F (the hydrodynamic force in water or aerodynamic force in air). This force can be decomposed into two components: a drag force (opposite to the direction of motion) and a perpendicular force: lift.

The hand’s angle of inclination is extremely important in producing propulsion by combining drag and lift forces. If the attack angle is too large, the swimmer uses the hand like a paddle rather than a propeller blade. With too little angulation, both lift and drag forces are weak, and the hand simply slips. For the swimmer, this means the hand’s orientation must be continuously adjusted with each change in the trajectory of the stroke. The angle of incidence relative to the hand’s path can range between 20° and 50° (Morouço et al., 2011, p. 167).

This adjustment is necessary because the hydrodynamic force, composed of drag and lift, determines the intensity and direction of the swimmer’s movement. To achieve maximum intensity, the force must be directed forward. Therefore, the swimmer must find an optimal technical finesse based on sensitivity or “feel” for the water.

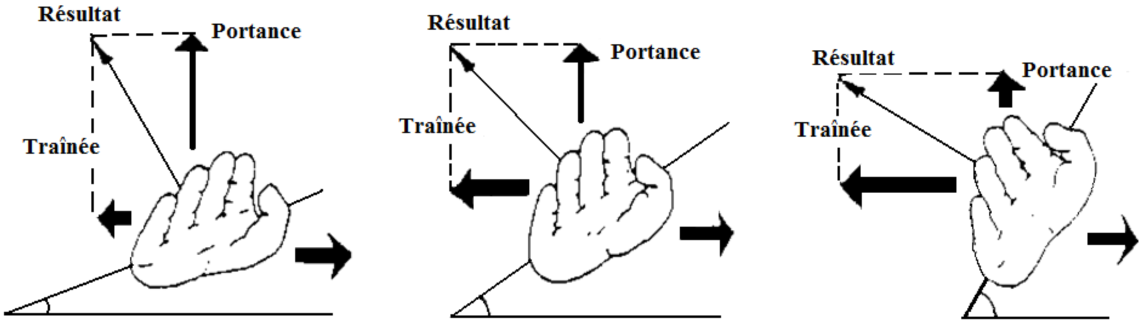


Figure 12: Hand inclination angle contributing to propulsive outcome by combining drag and lift (Colwin, 1982, cited by Chollet, 1997, p. 66)

However, some additional clarifications must be considered: the first concerns the respective directions of lift and drag. A constant relationship exists: lift always acts perpendicular to drag, which is always opposite to the direction of motion.

Two scenarios can occur: when movement is forward, lift is positive, as in an airplane wing; but it is also possible for lift to be negative, for example in an inverted wing or a downward-oriented wing.

- The second clarification: in the case of a swimmer, it is possible to dissociate the direction of the body's movement (forward) from the orientation of the propulsive surfaces (e.g., downward). In this case, if the hand moves along a downward trajectory, the drag will be directed upward, opposite to the motion; then, if the hand's orientation is correct, the lift will be directed forward.

This model is therefore based on two principles:

1. The orientation of the propulsive surfaces (e.g., the hands) should never be strictly perpendicular to the direction of movement, and the direction of the resulting propulsive force is not parallel to the displacement.
2. The swimmer does not push against a single mass of water but on a succession of different water masses. Therefore, the movement is not uniformly accelerated but occurs in a series of accelerations. The rhythm (sequence of stronger and weaker strokes) of the propulsive contacts will thus be variable (Chollet, 1997, p. 66).

Loetz et al. (1988, p. 61) studied the pressure peaks of the hand in all four strokes. They found that in breaststroke, there are two pressure peaks, and in the other three strokes, three pressure peaks. This confirms that elite swimmers rely on different water masses and that the rhythm of propulsive contacts is variable rather than uniformly accelerated.

However, this analysis should be considered cautiously from a learning perspective, as the integration of this technique is largely unconscious. Indeed, many swimmers who are unaware of these principles still compete at a high level. Therefore, this analysis is largely theoretical and difficult to apply directly for performance optimization.

2.5.2 Aquatic Propulsion Models

Six models are presented: four traditional (action/reaction) and two based on lift.

2.5.2.1 Traditional Models of Aquatic Propulsion

2.5.2.1.1 Paddle Wheel Model

Theoretical principle: This is based on Newton's third law, the law of action-reaction.

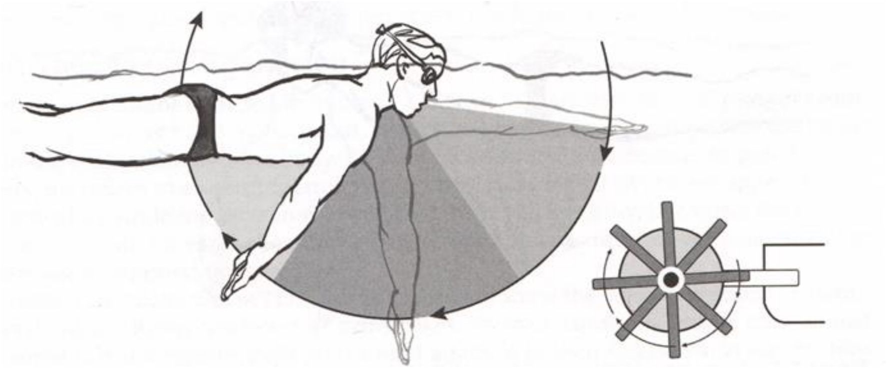


Figure 13: Arm-extended swimming corresponding to the paddle-wheel model (E.W. Maglischo, 2003, p. 7)

Swimming corresponding to this model can be characterized by a propulsive trajectory with arms fully extended. The use of this model in swimming is justified for beginners because it allows better perception of the movement when the arm is extended, as the shoulder proprioceptors are very precise. The negative consequence of this model is the significant strain on the shoulder muscles.

Moreover, while an increase in rotational speed initially improves the swimmer's forward velocity, very quickly this acceleration no longer affects the body's speed (Chollet, 1997, p. 69).

2.5.2.1.2 Rowing Model

This is still based on the action-reaction law, but with an added horizontal linear acceleration.

This acceleration generates support against the moving masses of water, and the reaction is the forward movement of the swimmer's body. Accelerating the propulsive contacts allows the propulsion forces to remain in contact with the fleeing water masses. The shoulder muscles are heavily engaged.

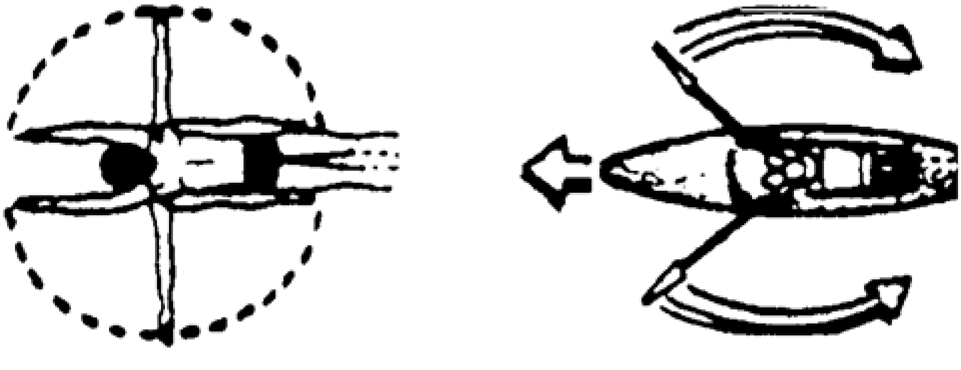


Figure 14: Horizontal arm stroke corresponding to the Rowing model
(According to P. Pelayo et al., 2000, p. 242)

2.5.2.1.3 Paddle Model

The logic of this model is to constantly seek out stationary masses of water and push them backward. A swimmer using this model performs a horizontal arm movement, moving their propulsive contacts in a sinusoidal pattern in order to engage stationary water masses and push them behind.

Figure 15: Swimming following a horizontal sinusoidal trajectory corresponding to the Paddle model (According to D. Chollet, 1997, p. 72)

There is a pursuit of better efficiency by mobilizing the propulsive surfaces toward stationary water masses (thus creating less “slippery” contacts). However, the trajectory is horizontal, and depth is not utilized (propulsion occurs in 2 dimensions).

2.5.2.1.4 Eskimo Roll Model

In this model, the paddle’s orientation is not only horizontal; the search for stationary water masses occurs in all three planes of space to create propulsive contacts. A swimmer using this model moves their arms in a curved S-shaped path across all three spatial planes.

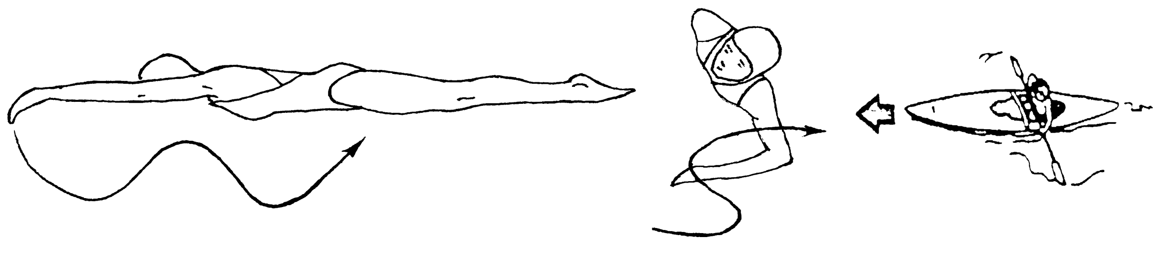


Figure 16: S-shaped hand movement in the 3 planes of space (D. Chollet, 1997, p. 73)

In traditional models of aquatic propulsion, the principle of orienting propulsive surfaces perpendicular to the direction of movement, with propulsive forces aligned parallel to the direction of movement, is fundamental.

Conversely, in lift-based models, the propulsive surface should never be at 90 degrees to the direction of the water flow generated by the push.

2.5.2.2 Models Based on Lift in Aquatic Propulsion

2.5.2.2.1 The Fin Model

In this model, the trajectories are constantly oblique, either with compensation of negative lift by positive lift (as in the dolphin undulation) or with positive lift predominating over negative lift (as in planing or surfing).

Figure 17: Swimming According to the Undulation or Fin Model (P. Pelayo et al., 2000, p. 242)

Two major applications of this model are used: one is the body undulation or leg kick, and the other is the oblique push of the upper limbs.

If undulation is more effective than arm and leg propulsion on the backstroke, this is likely due to the reduction of resistances to forward motion and the use of lift as a source of propulsion. Regulations have limited the use of this type of propulsion in backstroke events.

2.5.2.2.2 The Propeller or Sculling Model

This model is based on Bernoulli's principle. A propeller is essentially an ordinary screw, and its theory of action is the same. When a propeller rotates quickly in water, the surrounding water is set in motion at the same speed, and due to the reaction it exerts on the inclined surfaces of the propeller, it imparts forward motion to the boat. The faster the propeller spins, the faster the boat moves. The propeller's rotational movement, even when rapid, is constant; there is no acceleration. Since Bernoulli's time, the propeller has undergone continuous development, and the current ideal seems to be a variable-pitch propeller that adapts to speed to increase system efficiency.

In 1971, Counsilman, after observing underwater footage of elite swimmers, showed that their hands followed an S-shaped path. He concluded that the swimmer uses the hand like a propeller. Indeed, if the hand is properly angled relative to its trajectory in the water, it can act like a boat propeller and thus provide forward propulsion.

This propeller model has often been used to explain the propulsion logic of expert swimmers. In practice, the sculling model is equally interesting because it closely resembles natural swimming movements while still following the principle of pressure differences.

In a sculling motion that propels a vessel, the paddle is never perpendicular to either the direction of movement or the orientation of the stroke. In synchronized swimming, sculling movements with the hands are common. For example, the "forward" scull performed with the head in a dorsal position (arms along the body) involves the hands rotating (backs of the hands facing the thighs), palms angled toward the pool bottom (wrists flexed 45° upward), maintaining this angle as the forearms move outward simultaneously, then rotating the palms inward against the thighs. (Chollet, 1997, pp. 76-78)

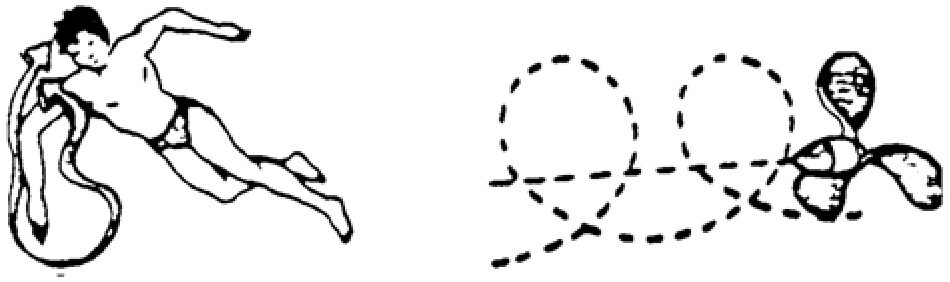


Figure 18: Hand Stroke Path Corresponding to the Propeller Model (D. Cholet, 1997, p. 77)

In competitive swimming (racing), sculling alone cannot provide the swimmer's full propulsion. Schleihauf (1986, p. 12) specifies that arm propulsion in swimming is derived from the combination of lift and drag forces. Both of these forces dominate at different times within the same stroke cycle. For example, lift forces dominate in breaststroke, while in freestyle, lift and drag forces each dominate in turn during different phases of the stroke.

The closer the hand exits the water to the point where it entered (marked, for example, by a float on the lane line), the greater its efficiency.

J.E. Counsilman (1977) further explains, in relation to the complementarity of lift and drag, that maximum propulsion efficiency in water is achieved by moving a large mass of water backward over a short distance rather than a small amount of water over a longer distance.

2.6 Common Principles Across the Four Competitive Strokes (Counsilman , 1986)

1. The hands do not move through the water in a straight line but follow a sinuous trajectory to push against "more stable" layers of water and to combine different hand angles for the optimal water catch.
2. The swimmer does not "pull and push" with fully extended arms but bends the elbow. This allows the hand to tilt and apply the full force backward.

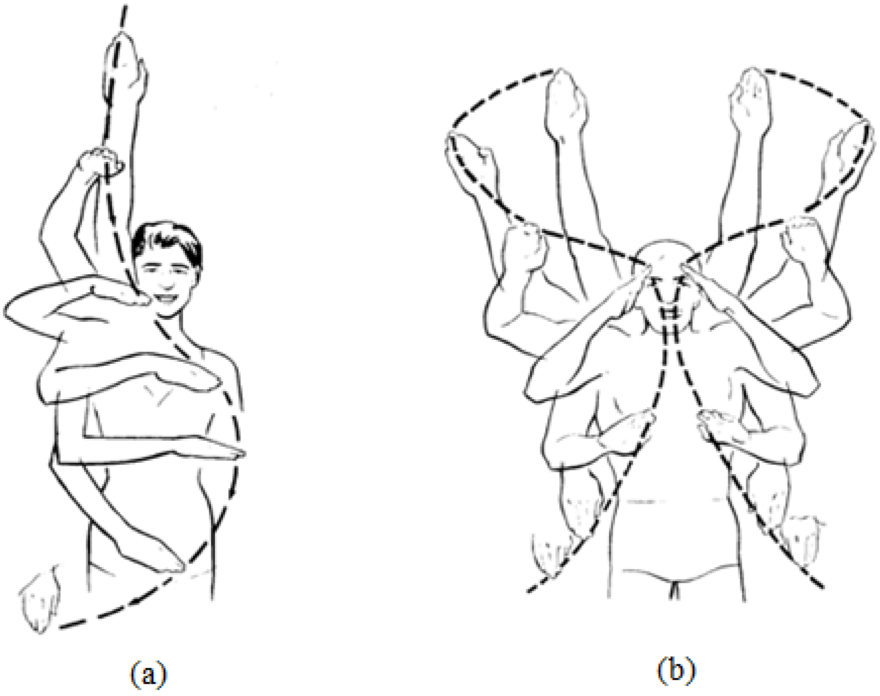

(a) (b)

Figure 19: Arm Trajectories in Freestyle (a) and Butterfly (b) (Underview)

3. The elbow must be kept high and forward (or elevated) during the “push” phase.
4. At water entry and exit, the hand must be angled appropriately to minimize the number of air bubbles created. In freestyle entry: lead with the thumb, fingers together, at an angle of 35°–45°; at exit, palm facing the thigh, pinky exiting first.
5. Hands must maintain the correct angle during the arm’s pull and push in the water to achieve maximum power (hand angle close to 37° relative to the trajectory).
6. Aim for the best possible hydrodynamic profile by reducing frontal drag and vortex drag (or tail suction).
7. Avoid pushing water back against the body during the stroke, as this increases resistance and slows forward progress. (Counsilman, 1986, pp. 92–100)

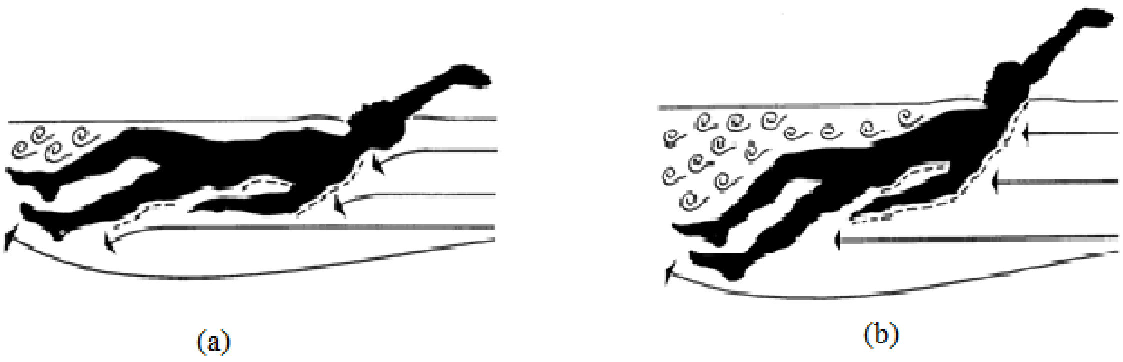

(a) (b)

Fig. 20**:** The swimmer (a) generates less frontal and vortical resistance than the swimmer (b).

2.7 Role of the Legs in Propulsion

In most swimming strokes, the arms are the primary source of propulsion. It has long been thought that the flutter kick was not a propulsive element in freestyle, backstroke, and butterfly.

According to Costill et al. (1994, p. 61), the main argument was that swimmers' leg movements in these strokes are not directed backward. Consequently, the leg kick only serves to stabilize the body during the swim. Other arguments indicate that leg kicks consume four times more oxygen than arm movements at the same swimming speed and significantly increase the energetic cost of swimming.

Today, the role of the legs in propulsion is being reconsidered. J.E. Counsilman observed during the qualifications for the 1976 Olympic Games that the majority of 100 m freestyle finalists, both men and women, used a six-beat kick per arm cycle, whereas for the 800 m and 1500 m events, a two-beat kick was more common (Counsilman, 1986, p. 118).

According to Cholet (1997, pp. 95–96), it is reasonable to consider that the longer the distance, the less significant the leg kick is in propulsion. This results from an efficiency issue: at the same speed, the leg kick requires more energy than arm movements. Therefore, in sprint events where maximum propulsion is advantageous (50 m, 100 m), the six-beat kick is primarily used. In endurance events, where energy management is critical (800 m, 1500 m), the two-beat kick is preferred. This is also due to the fact that the velocity produced by propulsive actions is not constant throughout a stroke cycle. Variations in the center-of-gravity velocity during an arm cycle are greater than those produced by a six-beat kick.

Two cases can then be distinguished:

1. **Case 1:** The maximum velocity of the center of gravity remains lower than the minimum velocity produced by the arms. In this case, the legs have no direct propulsive effect. This occurs in middle-distance swimmers, who maintain excellent continuous arm movement while their leg actions are minimally propulsive.
2. **Case 2:** The maximum velocity of the center of gravity exceeds the minimum velocity produced by the arms. In this case, the legs contribute directly to propulsion. This is particularly true for sprint swimmers with effective arm-leg coordination and powerful kicks.

Thus, the propulsive role of the kick is primarily linked to the relative efficiency between leg-only and arm-only propulsion, but it is also influenced by the intermediate "gaps" in the propulsive actions of each arm.

2.8 Course Objectives

At the end of this course, students should be able to:

1. Understand the fundamental biomechanical principles governing swimming.
2. Analyze the forces acting on a swimmer, including propulsion, drag, and lift, and their interactions with body positioning.
3. Explain the hydrodynamic laws (Newton’s laws and Bernoulli’s principle) that influence swimming efficiency.
4. Assess the role of buoyancy, equilibrium, and body alignment in optimizing swimming performance.
5. Apply biomechanical principles to improve swimming technique and minimize resistances in water.
6. Relate respiratory patterns and visual orientation to equilibrium and propulsion during swimming.

2.9 Evaluation Methods

Continuous Assessment (CA): 40%

- Participation in practical sessions and in-class exercises: 10%
- Lab reports or analysis of swimming movements: 15%
- Quizzes on theoretical principles: 15%

Final Exam: 60%

- Written theoretical exam (understanding of forces, hydrodynamics, propulsion and resistances): 40%
- Practical assessment (analysis of swimming technique, application of biomechanical concepts): 20%

Online Resources:

- International Swimming Federation (FINA) technical rules and biomechanics guides.
- Research articles on PubMed and ResearchGate on swimming propulsion and drag forces.

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Chapter 3: Analysis of Swimming Techniques

Introduction

The swimming techniques addressed in this chapter are very closely linked to the requirements of the task namely, moving as fast as possible in accordance with regulations and the individual's capabilities (anatomical, energetic, motivational, etc.).

Thus, unlike *style* (which represents an individual response), the "correct" technique does not exist in absolute terms. It can only exist in relation to the demands of the task and the swimmer's capabilities. Whether the swimmer is relaxed, highly motivated, or under stress, the technique used cannot be the same. It is therefore inappropriate to attempt to formalize or reproduce a technique that is very unlikely to be fully suited to every situation or every swimmer.

However, the modeling of technique, based on sound biomechanical knowledge, makes it possible to position a performance in relation to constants derived in particular from the field of high-level performance. This notion of modeling must be understood in its broadest sense. The definition of a model should not be accepted as something that serves or must serve as an object of imitation, but rather as a simplified representation of a process.

This modeling of technique is justified as a system of simplification, as a concrete representation of scientific laws, as a means of objectifying the constants of motor responses adapted to given tasks, and finally as a set of explicit reference points allowing the positioning of any corresponding behavior.

If our objective is to provide a scientific contribution, it is precisely to allow a better understanding of techniques adapted to different swimming strokes, their evolution, and any potential discrepancies between what might appear logical and concrete reality. Indeed, in our view, in order to intervene in a technique, one must first be capable of analyzing it in a sufficiently precise and objective manner.

Concept of Technique

The term *technique*, derived from the Greek *tekhnikos*, from *tekhnê*, meaning *art*, refers to the set of procedures and practical means specific to an activity (Dictionary definition).
Technique is individual experience, depersonalized, transmitted, and accumulated; it is a way of doing that is separated from the reasons for doing, an act stripped of its motives (Fabre, cited by Catteau & Garoff, 1986, p. 139).

Sporting technique refers to the procedures generally developed through practice in order to solve, in the most rational and economical way, a specific motor problem. The technique of a sporting discipline corresponds to a succession of ideal motor coordinations which, while preserving their gestural characteristics, may undergo modifications allowing adaptation to the characteristics of individual personality or personal style (Weineck, 1997, p. 417).

Body technique corresponds to the set of transmissible means implemented by humans in order to perform a given motor task as efficiently as possible (Vigarello & Vives, 1983, p. 45).

3.1 Front Crawl (Freestyle)

This swimming style is better known as “freestyle.” In official regulations, crawl as such does not exist; the term used is *freestyle*. It was coaches and swimmers who chose the crawl technique as the fourth stroke because it remains the most efficient and the fastest style (Refuggi & Chifflet, 1998, p. 78).

In freestyle events, contrary to what one might believe, there is in fact no real choice: if one wishes to be efficient and competitive, one swims crawl. This is why crawl has become synonymous with freestyle. There is no official regulation governing crawl itself; the regulations established for freestyle prevail.

Freestyle means that in an event designated as such, the swimmer may use any swimming style, except in individual medley or medley relay events, where freestyle refers to any style other than backstroke, breaststroke, or butterfly (Lacoste & Semerjian, 1998, p. 57).

3.1.1. Body Position

The body must be balanced in a horizontal position in order to reduce resistance to forward motion. It is important to maintain good horizontal and lateral alignment, as well as sufficient shoulder roll, while limiting lateral and frontal oscillations of the rest of the body.

The body surface perpendicular to the direction of motion should be as small as possible. The form of water entry must also aim to reduce resistance to forward motion. Maximum body elongation is another factor that promotes propulsion.

The reference position is prone (ventral), insofar as human joint capabilities allow upper-limb movements in the anterior plane that are far more effective than those performed in the posterior plane of the body (Chollet, 1997, p. 106).

3.1.2. Arm Movement

The underwater arm movement in front crawl consists of three diagonal sweeps: a downward sweep, an inward sweep, and an upward sweep. The entry and extension, as well as the release and recovery, will also be described.

3.1.2.1 Entry and Extension

The swimmer immerses the hand, then the wrist and elbow, into the water and extends the arm into the initial position of the propulsive phase. Upward rotation of the scapula allows the swimmer to reach an elongated position in the water (McLeod, 2012, p. 3).

This action conditions the entire movement. The elbow, positioned ahead of the head, effectively guides hand entry and extension with minimal turbulence. Extension occurs along the body’s axis during the final part of the propulsive movement of the opposite arm. It allows body stabilization and the transmission of velocity (Pedroletti, 2000, p. 108).

Entry occurs directly in front of the swimmer’s shoulder, with the elbow slightly flexed and the palm facing outward. This allows the hand to slip into the water on its edge, followed by the arm entering nearly the same portion of water.

A bow wave is produced if the swimmer pushes the hand forward through the water during entry. Conversely, a streamlined entry minimizes this drag. Swimmers must ensure that their hand does not cross in front of the face during entry, as this would cause lateral body oscillation. Instead, the hand should enter somewhere between the midpoint of the head and the top of the shoulder on the same side.

After entry, the arm is extended almost straight forward just beneath the water surface. During arm extension, the palm faces downward (Maglischo, 2003, p. 103).

3.1.2.2 Downward Sweep and Catch

The downward sweep should begin immediately after the propulsive phase of the opposite arm has ended. The lead arm performs a curvilinear downward sweep until the moment of the catch.

The swimmer gradually flexes the elbow during the downward sweep in order to bring the arm directly backward at the moment of the catch. This occurs near the end of the sweep when the elbow is positioned above the hand and the arm and forearm are oriented backward (Costill et al., 1994, p. 66).

Following the catch, the hand gradually accelerates while moving downward and slightly outward with a slight elbow flexion. The relaxed hand takes a spoon-like shape. The palms are oriented downward, outward, and backward. This sweep is the least propulsive, but it is decisive in positioning the arm and hand optimally for the sculling action that follows (Pedroletti, 2000, p. 108).

The hand is inclined so that the palm faces diagonally outward. If the hand were held flat during entry, the mass of air bubbles dragged along would be so great that underwater pulling efficiency would be compromised. Therefore, the hand must be held at an angle of approximately 45° relative to the water surface, with the thumb leading the entry. This minimizes air entrainment (Counsilman, 1986, p. 104).

The movement is initiated by the clavicular portion of the pectoralis major, rapidly assisted by the latissimus dorsi. These two muscles generate most of the force applied during underwater arm traction, particularly during the second part of the movement. Wrist flexors maintain slight wrist flexion throughout the propulsive phase. Elbow flexors (biceps brachii and brachialis) contract at the beginning of the catch phase and progressively bring the elbow from full extension to approximately 30° of flexion (McLeod, 2012, p. 3).

3.1.2.3 Inward Sweep

Upon reaching the deepest point, the hand movement curves around the wrist, orienting the palm inward, upward, and backward. The trajectory following the hand also curves inward, upward, and backward. Hand speed accelerates until it aligns with the body’s longitudinal axis (Pedroletti, 2000, p. 110).

According to Counsilman (1986, pp. 104–106), any conception of a straight-line underwater arm trajectory must be rejected. Photographic analysis of numerous swimmers shows that the arms never follow a perfectly straight path but instead describe a sinuous curve.

Some swimmers use a variation resembling an S-shaped trajectory. The amplitude of the curve varies among swimmers, likely depending on strength, flexibility, or other factors. Another misconception must be dismissed: elbows should not remain fully extended during the entire propulsive phase. In fact, the arm flexes at the elbow to varying degrees throughout most of the movement.

The outward sweep illustrated in Figure 1 is the first propulsive movement in crawl. It is also semicircular, beginning at the catch and continuing until the arm reaches the body's midline or slightly beyond. The arm, flexed at the catch, flexes further during the inward sweep to reach approximately 90° at the end. The palm gradually turns inward and upward by the end of the movement.

Swimmers should moderately accelerate their hands from the beginning to the end of the inward sweep. However, maximum hand speed should not be reached at this stage, but rather during the following phase (Monteil & Rouard, 1994, p. 57).

3.1.2.4 Upward Sweep

Under the chest, the palm initially turns outward and backward. Subsequently, it turns upward and outward as it disengages from the body. Following the arm sweep, the arm extends and externally rotates while moving upward and outward (Pedroletti, 2000, p. 110).

The upward sweep is the second and final propulsive sweep in crawl. It begins at the end of the preceding sweep. Orientation shifts rapidly from inward to outward by rotating the hand. The swimmer moves the arm upward, outward, and backward toward the surface. The upward sweep ends when the hand reaches the level of the thigh—not the water surface. The arm extends during this sweep, but not fully, contrary to a widespread belief. Hand speed reaches its maximum during this movement (Costill et al., 1994, p. 68).

During the final part of the propulsive phase, the triceps brachii extends the elbow, bringing the hand backward and above the water, thus concluding the propulsive phase. The degree of elbow extension depends on swimming technique and the timing of arm exit (McLeod, 2012, p. 3).

3.1.2.5 Release and Recovery

The release phase begins before the swimmer's hand exits the water. It starts when the elbow emerges during the upward sweep. At this point, the swimmer begins flexing the arm to bring it forward while the hand is still underwater.

The overlap between the end of the upward sweep and the beginning of recovery preserves angular momentum and reduces muscular effort needed to overcome arm inertia and redirect it forward. Pressure should be released as the hand crosses the thigh (with the elbow already out of the water). The palm turns inward so that the hand presents its edge to the water surface, minimizing resistance.

Once out of the water, the arm is brought forward for the next cycle using the traditional high-elbow recovery. Progressive elbow flexion allows the arm to continue moving upward and forward after leaving the water and prevents excessive lateral swing. Although the arm naturally tends to swing outward in a circular motion, swimmers must concentrate on directing it as straight forward as possible. Excessively low or wide recovery disrupts body alignment.

Body rotation is also essential for effective recovery. Swimmers must rotate toward the recovering arm so that the shoulder on that side is higher, facilitating high elbow position and a straighter forward arm path.

The goal of recovery is to position the arm for the next cycle. It is an important but non-propulsive function. Recovery should return the arm above water without disturbing lateral alignment and allow temporary muscular relaxation. Swimmers should use minimal force and focus on accelerating the propulsive phase rather than recovery. Recovery speed will naturally adjust to match the opposite arm, preventing energy waste and alignment disruption (Maglischo, 2003, p. 113).

The transition between the end of the push and the recovery occurs as the hand changes orientation. Momentum gained during underwater traction and push continues seamlessly into recovery. At the end of the push, the palm faces directly backward, then rotates inward toward the thigh. The little finger exits the water first, followed by the hand slicing vertically through the surface like a knife, minimizing resistance (Counsilman, 1986, pp. 101–104).

The primary muscles active during recovery are the deltoid and the rotator cuff (supraspinatus, infraspinatus, teres minor, subscapularis), lifting the arm and hand out of the water near the hips and overhead for the next entry (McLeod, 2012, p. 3).

3.1.2.6 Arm Synchronization

In crawl, arm movements are alternating: when one arm is propulsive, the other is in recovery. Several muscle groups act as stabilizers during both phases, the most important being the scapular stabilizers (pectoralis minor, rhomboids, levator scapulae, middle and lower trapezius, serratus anterior). These muscles stabilize the scapula, which is essential since propulsive forces depend on solid scapular support. Scapular stabilizers also work with the deltoid and rotator cuff to reposition the arm during recovery (McLeod, 2012, p. 3).

Precise interrelations between the two arms are critical for swimming speed. Alternating arm movements must be coordinated with body rotation to facilitate the three sweeps and maintain a streamlined position. The most important event is that the lead arm should enter the water when the opposite arm is midway through the inward sweep. This allows body rotation toward the propulsive side in preparation for the upward sweep. Additionally, the lead arm must not begin the downward sweep until the opposite arm has completed the upward sweep (Maglischo, 2003, p. 115).

According to Chollet (1997, pp. 107–108), three main coordination patterns exist in crawl:

- **Catch-up coordination**: one arm pauses during the other’s propulsive phase. This promotes body elongation but disrupts motor continuity.

- **Opposition coordination**: propulsive actions alternate like a relay; advantageous when supported by active leg action.

- **Overlap coordination**: partial overlap of propulsive phases. Often associated with reduced leg action and middle-distance swimming, offering energetic advantages but reducing the catch phase.

3.1.3. Leg Kick

The legs perform alternating regular kicks, passing close to each other. When aligned, they should extend roughly along the body's transverse axis so that propulsion acts on the center of gravity (Lewin, 1981, p. 80).

The entire leg is involved from hip to ankle. Toes should just skim the surface. Air bubbles facilitate movement. Although leg kicking is not highly propulsive, its quality greatly influences arm propulsion efficiency (Lacoste & Semerjian, 1998, p. 59).

Like arm movements, leg kicks include propulsive and recovery phases. The recovery phase begins at the hips with contraction of the gluteal muscles, followed by the hamstrings, functioning as hip extensors (McLeod, 2012, p. 3).

3.1.3.1 Downward Kick

The downward phase begins at the hips through activation of the iliopsoas and rectus femoris. The quadriceps assist knee extension, providing additional power (McLeod, 2012, p. 3).

This whipping movement starts with hip flexion followed by knee extension. The leg begins its downward kick before reaching the peak of the previous upward kick. Proper relaxation allows water pressure to rebound the leg upward before an active downward whip.

3.1.3.2 Upward Kick

At the end of the downward kick, the leg rebounds upward with the knee extended. Water pressure maintains leg extension and positions the foot naturally. The upward kick ends when the leg aligns with the body and the thigh begins hip flexion, initiating the next downward kick.

Throughout kicking, knee and ankle muscles remain relaxed except at the end of the downward kick, where strong extension and plantar flexion occur. Primary muscles involved are hip flexors and extensors (Costill et al., 1994, p. 71; McLeod, 2012, p. 3).

3.1.3.3 Kick Amplitude

Kick amplitude should be neither too deep nor too shallow. Optimal width ranges between 50 and 80 cm. Cureton (1930) recommended a maximum of 61 cm, while Allen (1948) found 36 cm superior to 15 cm for propulsion.

The kick must stabilize and propel without increasing drag. The foot should lightly break the surface during the upward kick; excessive height pushes the body downward. At the end of the downward kick, the foot should be just below the body line (Maglischo, 2003, p. 123).

3.1.4. Breathing

The need for oxygen forces swimmers to bring airways to the surface. Breathing should disrupt body balance as little as possible. Inhalation must be rapid, with the mouth wide open. Swimmers use the bow wave created by head movement, rotating rather than lifting the head (Catteau & Garoff, 1986, pp. 161–162).

The head should not be too high; a lower position improves hydrodynamics. Excessive head lift causes hip sinking and increased resistance. Inhalation occurs during a brief window when the mouth clears the surface; exhalation occurs underwater, slowly at first, then forcefully just before inhalation (Counsilman, 1986, pp. 114–116).

Breathing should occur during the first half of recovery, with the face returning to the water during the second half, coordinated with body rotation to optimize alignment for the upward sweep.

Most swimmers breathe once per stroke cycle on the same side. Some use bilateral breathing (every three strokes). While conventional breathing is recommended, especially beyond 100 m, some swimmers perform better with alternate breathing despite reduced oxygen intake (Costill et al., 1994, pp. 74–75).

In freestyle events from 50 to 1500 m, breathing patterns vary. Sprinters minimize breathing, while distance swimmers breathe more frequently, often every stroke before and after turns (Pelayo & Wojciechowski, 1991, p. 30).

3.1.5. Arm Leg Coordination

Motor solutions for arm–leg coordination typically involve three rhythms: six-beat, four-beat, and two-beat patterns.

3.1.5.1 Six-Beat Kick

Each leg performs three kicks per arm cycle, totaling six kicks per cycle. Often used by sprinters, though some distance swimmers also use it (Counsilman, 1986, p. 121).

Each downward kick aligns with one of the three arm sweeps. Timing is precise, making this rhythm theoretically ideal, although elite swimmers succeed with other rhythms as well (Costill et al., 1994, p. 75).

3.1.5.2 Two-Beat Kick

Used by many swimmers, especially women. One kick occurs per arm stroke. Legs move almost straight up and down without crossing (Counsilman, 1986, p. 120).

This rhythm requires less energy and is common in distance swimming. Greater natural buoyancy reduces the need for strong leg action. Men often prefer four-beat or crossed two-beat rhythms to prevent leg sinking (Costill et al., 1994, pp. 75–76).

3.1.5.3 Crossed Two-Beat Kick

Primarily used by male swimmers. One leg crosses over the other during the kick, alternating sides. The crossing leg corresponds to the active arm. This rhythm suits swimmers whose legs tend to sink with a standard two-beat kick (Counsilman, 1986, p. 120).

3.1.5.4 Four-Beat Kick

A combination of six- and two-beat rhythms. Swimmers use six-beat kicking on one arm stroke and two-beat on the other. Many swimmers adopt a two-beat rhythm on the breathing side, possibly to facilitate inhalation (Costill et al., 1994, p. 76).

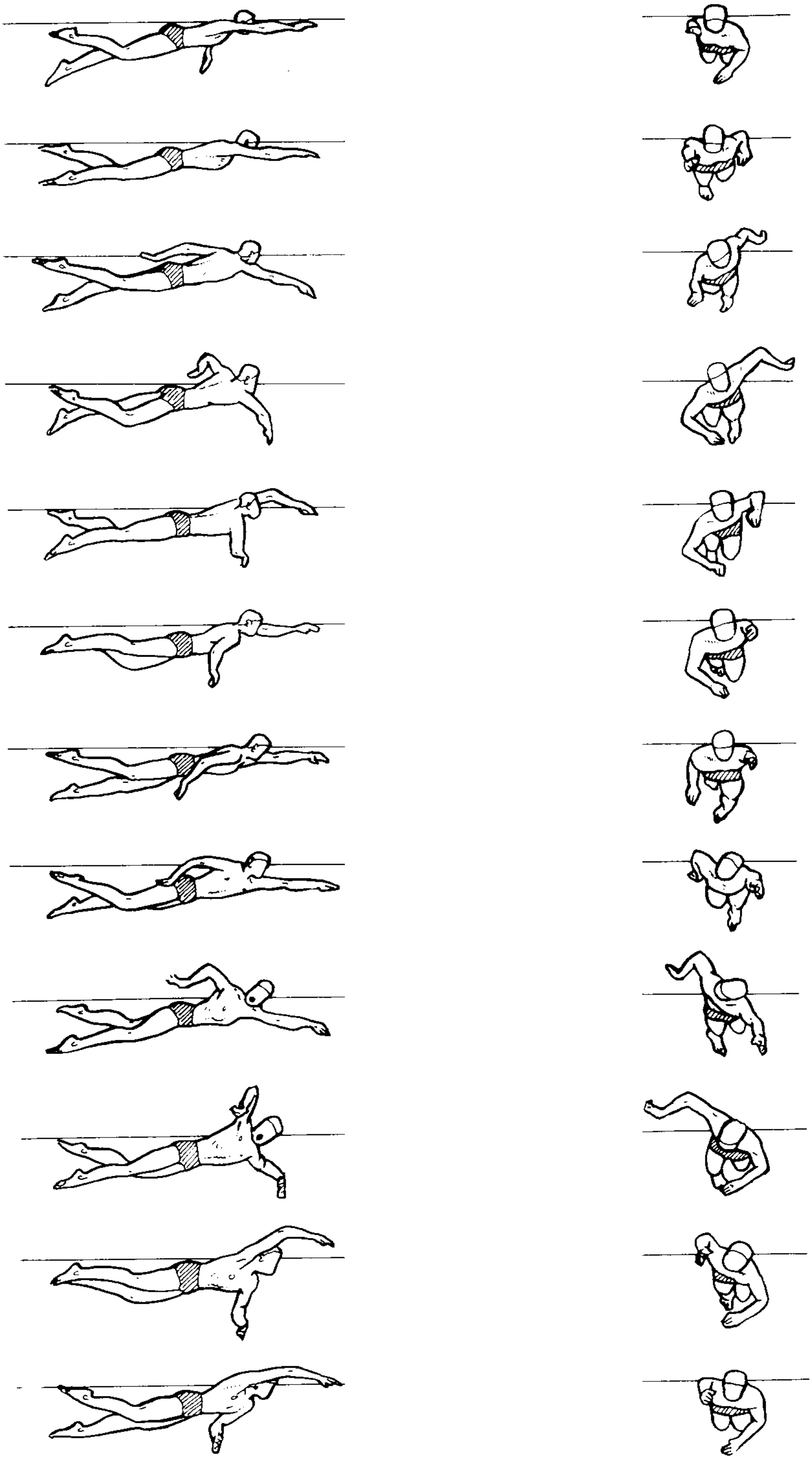

Figure No. 1: Illustration of the front crawl technique

3.2 Backstroke

Backstroke is an alternating swimming stroke involving both the arms and the legs. The arm movement consists of an underwater propulsive phase and an aerial recovery phase. The legs play a dual role: propulsion and, above all, body balance and stabilization. (Lacoste & Semerjian, 1998, p. 47)

3.2.1. Body Position

The swimmer lies in a dorsal position in the water. To achieve an advantageous hydrodynamic position, the head is slightly raised toward the thorax so that the ears remain submerged. (Lewin, 1981, p. 85)

As in front crawl, body balance should be horizontal to reduce forward resistance. Maintaining good horizontal and lateral alignment is essential. Shoulder roll becomes more pronounced in backstroke to position the propulsive surfaces for maximum efficiency, despite joint limitations, and also to facilitate shoulder clearance during the recovery phase. This roll must be properly controlled to minimize resistance. Reducing the frontal surface area, improving body entry shape, and maximizing body length are key objectives. (Chollet, 1997, pp. 111–112)

3.2.2. Arm Movement

The arm technique in backstroke consists of four underwater sweeps and a recovery phase.

3.2.2.1 First Downward Sweep

Shoulder rotation places the hands so that the little finger enters the water first, with the palm facing outward. The elbow remains extended, and the swimmer adopts a stretched position to begin the underwater propulsion phase. Unlike front crawl or butterfly, the initial pushing component in backstroke is dominated by the latissimus dorsi, while the contribution of the pectoralis major is reduced. Nevertheless, both muscles remain the primary motor muscles and are involved to varying degrees throughout the propulsive phase. (McLeod, 2012, p. 5)

After water entry, the swimmer’s arm performs a downward and outward sweep to establish the catch position. This occurs when the hand reaches its deepest and widest point. Following the catch, aided by shoulder rotation, the hand moves downward and outward with slight elbow flexion. This movement is primarily produced by shoulder rotation rather than a rigid arm press. The deepest point of the hand is between 45 and 60 cm, depending on body and shoulder roll. Elbow flexion helps prevent excessive lateral deviation of the hand. (Pedrolletti, 2000, pp. 136–137)

3.2.2.2 First Upward Sweep

The first upward sweep is the initial propulsive phase. It begins at the catch. The swimmer performs a semi-circular movement upward and backward. While wrist flexors remain active throughout propulsion, the wrist stays neutral to slightly extended. Due to water pressure and activation of the biceps brachii and brachialis, the elbow flexes to approximately 45° at the start of the pull and may reach 90° by the end of the phase. (McLeod, 2012, p. 5)

The aquatic pull begins once the arm reaches a depth of 20–30 cm. The elbow starts extended and progressively flexes as the arm moves backward, reaching a maximum flexion of 90–100° at mid-pull (start of the push), then extending again toward full extension at the end of the push. During the pull, the upper arm undergoes medial rotation, placing the elbow in an “inverted high” position. (Counsilman, 1986, pp. 126–127)

3.2.2.3 Second Downward Sweep

The swimmer performs a second downward sweep, beginning when the hand reaches the highest point of the previous sweep. The arm follows a semi-circular path downward and backward until it is fully extended below the thigh. The hand, previously oriented upward, turns downward toward the pool bottom. Fingertips remain oriented laterally throughout the movement.

Hand speed decreases during the transition into this sweep, then progressively increases to reach maximum velocity at the end of the movement. (Maglischo, 2003, p. 193)

3.2.2.4 Second Upward Sweep

For many years, it was believed that propulsion ended with the second downward sweep. Recent findings show that swimmers can still generate propulsive force as the arm moves toward the surface.

From the end of the previous sweep, the swimmer performs an upward, backward, and inward sweep until the hand reaches the back of the thigh. Recovery begins from this point. The hand then moves forward and upward, and no further propulsion is produced.

During this sweep, the wrist is hyperextended so that the palm faces backward and slightly upward, while the fingers point downward. Hand speed decreases markedly during the transition, then accelerates to a maximum at the end of the movement. The wrist becomes the leading edge, while the fingers act as the trailing edge, directing water backward and downward. Not all swimmers use this phase for propulsion; some initiate recovery immediately after the second downward sweep. (Maglischo, 2003, p. 194)

3.2.2.5 Relaxation, Recovery, and Water Entry

The aerial recovery begins while the hand is still in the water. At the end of the push, the swimmer presses water downward, causing body roll and elevating the shoulder on the same side, which facilitates arm exit. The palm then turns toward the thigh, thumb upward, and the hand exits led by the thumb. Recovery is performed with the elbow fully extended, with the arm swinging vertically upward and forward. (Counsilman, 1986, p. 122)

Pressure on the water should be released near the lower thigh. The hand turns inward and exits edge-first to minimize drag. The thumb exits first, not the little finger. Hand speed decreases significantly during recovery. Continuous shoulder roll assists arm exit with minimal effort.

The arm moves upward and forward above the water, remaining high to avoid lateral body deviation. The palm faces inward during the first half of recovery and outward during the second half. Recovery should be quick yet smooth, with muscles as relaxed as possible.

Water entry occurs with full arm extension directly in front of the shoulder, palm oriented outward to minimize turbulence. (Costill et al., 1994, p. 93)

3.2.2.6 Arm Synchronization

Unlike front crawl, where several coordination patterns may be effective, backstroke requires opposition coordination. Shoulder anatomy necessitates significant upper-body roll to enhance propulsion and facilitate opposite-arm recovery. In this coordination, when one arm reaches the highest point of recovery, the other begins its final underwater sweep. Hand entry of one arm occurs as the opposite arm completes its final sweep. (Chollet, 1997, p. 113)

3.2.3. Leg Kick

The backstroke kick combines characteristics of front crawl and butterfly. Like crawl, the kick is alternating, but due to the swimmer's dorsal position, most propulsive force is generated during the upward phase rather than the downward phase. Dolphin kicking is also used after starts and turns. Muscle activation patterns are similar, with directional differences due to body orientation. (McLeod, 2012, p. 5).

3.2.3.1 Upward Kick

The upward kick is a whip-like extension beginning with hip flexion, followed by knee extension, and ending with partial ankle flexion. The kick starts as the foot passes under the hips during the preceding downward kick. The thigh rises as the lower leg and foot remain relaxed, allowing water pressure to flex the knee and plantar-flex the ankle.

The thigh continues rising above hip level, after which the leg extends diagonally upward toward the surface until fully extended just below the water. Legs are more flexed during the upward kick in backstroke than during the downward kick in crawl, enhancing propulsion. (Costill et al., 1994, p. 94)

3.2.3.2 Downward Kick

The downward kick is a rebound-like action following the upward kick. The leg glides downward in extension, with the foot in a neutral position maintained by water pressure. The movement ends when the leg passes beneath the body, at which point hip flexion begins the next upward kick. (Costill et al., 1994, p. 94)

3.2.4. Arm Leg Coordination

Coordination between arms and legs occurs naturally through action–reaction mechanics. During the second half of the underwater arm movement, the hand pulls the hip on the same side. To counter lateral oscillation, the swimmer performs an upward kick with the opposite leg, canceling rotational torque. (Counsilman, 1986, p. 131)

Six kicks per arm cycle are more consistent in backstroke than in crawl, with greater amplitude. Superimposing arm and leg diagrams helps illustrate synchronization. (Catteau & Garoff, 1986, p. 181)

3.2.5. Breathing

Breathing difficulties are minimal compared to other strokes, as the mouth and nose are usually above water. Breathing rhythm is linked to arm movement. Inhalation occurs through the mouth, exhalation through the mouth and nose. Typically, swimmers inhale during the recovery of one arm and exhale during the recovery of the other. This pattern prevents breathlessness and shallow breathing. (Lewin, 1981; Counsilman, 1986).

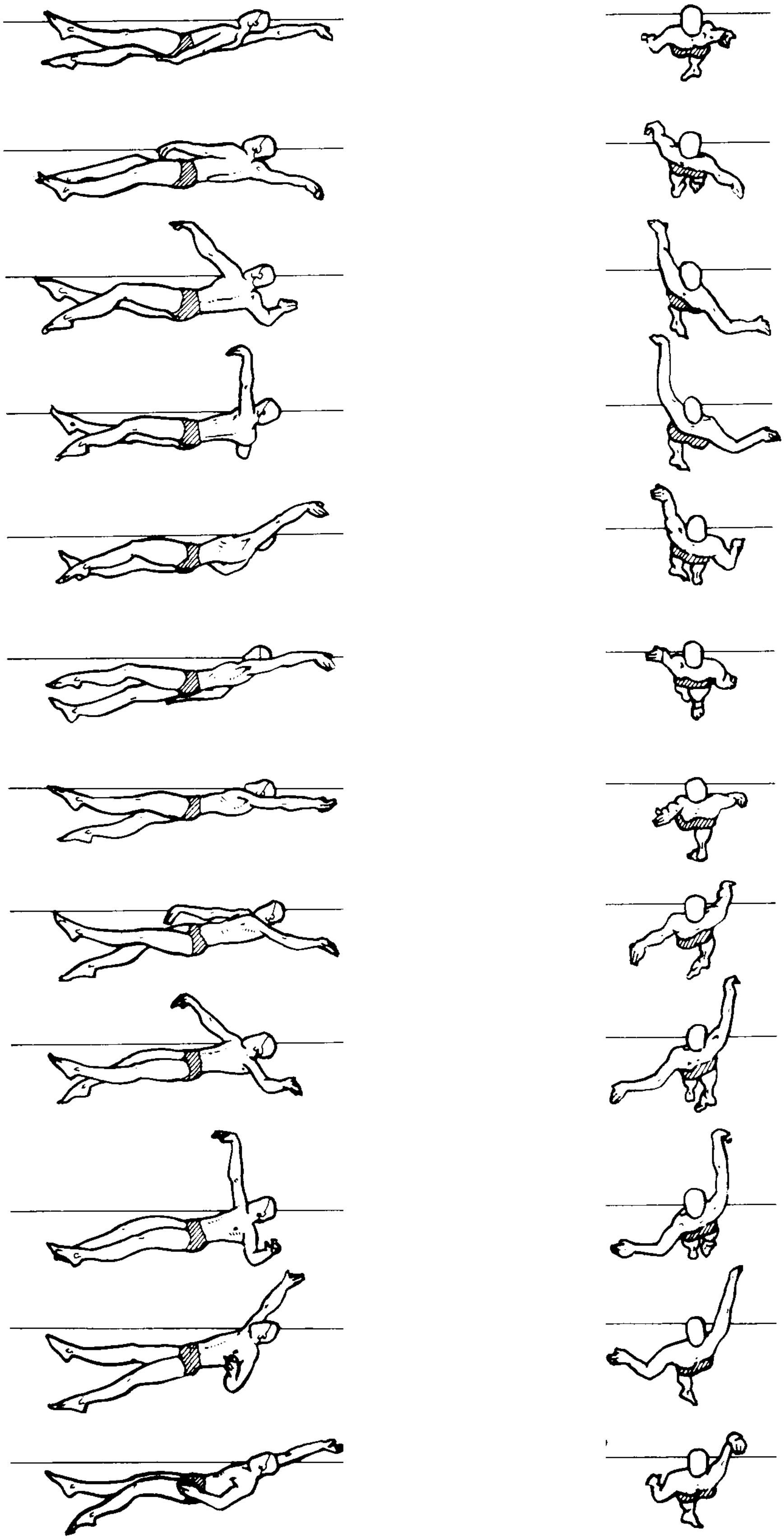

Figure 2: Illustration of Backstroke Technique

3.3 Breaststroke

Breaststroke is the only swimming stroke in which the legs are as effective as the arms in terms of propulsion. This stroke is also characterized by the absence of an aerial recovery of the arms (with rare exceptions among certain elite swimmers who project their arms just above the water surface) (Lacoste & Semerjian, 1998, p. 72).

After the start and after each turn, the swimmer may perform one arm movement extending to the legs, during which the swimmer may be completely submerged. After the start and after each turn, a single butterfly kick is allowed at any time before the first leg movement. The head must break the surface of the water before the hands turn inward at the widest point of the second pull. From the start and throughout the race, the movement cycle must include one arm movement and one leg movement in that order. All arm movements must be simultaneous and in the same horizontal plane, without alternating motion (World Aquatics. Rules, 2023-2025).

Although breaststroke swimmers are capable of generating greater force during the propulsive phases than swimmers using other techniques, they noticeably decelerate each time they bring their legs back to prepare for the next kick. This consequently reduces the average speed per cycle well below that of the other strokes.

3.3.1. Body Position

Breaststroke, originally a horizontal stroke but one that generates significant resistance to forward motion particularly during leg recovery has progressively evolved toward a more pronounced vertical orientation. Flat (horizontal) breaststroke gives relatively balanced importance to arm propulsion and leg propulsion. Vertical breaststroke is characterized by a marked lifting of the upper body and a forward “dive” that allows the swimmer to return to a hydrodynamic position. An upward dolphin kick complements this structure (Chollet, 1997, p. 124).

More than any other swimming stroke, breaststroke technique evolves very rapidly. Experts disagree on the relative effectiveness of a very flat swimming style versus a highly undulating style closer to butterfly. A recent rule change has led more swimmers to adopt an undulating style. This regulatory change allowed swimmers to submerge their head during certain parts of the cycle, thereby enabling greater freedom of body movement. The undulating style, currently the most popular, is known as the *wave motion*. Many elite swimmers have adopted this style or other techniques incorporating undulation (Costill et al., 1994, pp. 87–108).

3.3.2. Arm Movement

The arm movement in breaststroke consists of four phases: the outsweep, the catch, the insweep, and the recovery.

3.3.2.1. The Outsweep

Swimmers begin the outsweep by gliding the arms outward and forward at full extension. At the end of the recovery phase, the hands should trace a semi-circular path, sweeping outward, forward, and slightly upward until the arms are positioned outside the shoulders, where the catch will be performed.

During the outsweep, swimmers should flex the arms at the elbow in order to position them facing backward as early as possible. The swimmer performs the outsweep to reach the catch position, which occurs when the hands are outside the shoulders and facing backward. The arms remain extended for most of this sweep, although they flex slightly in preparation for the propulsive phase as they approach the catch position.

At the beginning of this sweep, the hands should be oriented downward. They rotate outward as they approach the catch position so that they are oriented outward and backward at the end of the outsweep.

The outsweep is not propulsive; therefore, swimmers should perform it smoothly and slowly. Its purpose is to correctly position the arms for the following phase, the insweep (Maglischo, 2003, p. 232).

3.3.2.2. The Insweep

The insweep is the only propulsive phase of the arm movement. It begins once the catch is established, with the arms positioned outside the shoulders. At this moment, swimmers should perform a wide semi-circular sweep directed downward and inward, then upward, until the arms are close to the shoulders. The insweep should stop just before the swimmer’s hands meet.

From the catch position, the arms continue to flex, reaching an angle greater than 90° at the end of the insweep. The palms, initially facing outward, gradually rotate inward during this sweep. Hand speed should increase progressively throughout the insweep, reaching a maximum as the hands approach each other (Maglischo, 2013, p. 6).

The first part of the underwater pull is similar to that of front crawl and butterfly. The movement is initiated by the clavicular portion of the pectoralis major, quickly joined by the latissimus dorsi. During the second part of the pull, powerful contractions of the pectoralis major and latissimus dorsi draw the arms and hands toward the body’s midline to complete the pull. The forces produced during the final phase propel the body forward and lift the trunk upward, a movement aided by contraction of the paraspinal muscles. The swimmer thus raises the head and shoulders out of the water. Flexion and rotation at the elbows bring the hands toward the midline of the body, marking entry into the recovery phase (McLeod, 2012, p. 6).

The catch is performed with the arms fully extended in front of the swimmer, with the hands touching. The hands establish support and initiate the pull at a depth of approximately 15 to 25 cm, not just below the surface as many swimmers believe. From the start of the pull, the hands should incline so that the palms are oriented diagonally outward at an angle of approximately 45 degrees.

As the pull begins, the hands are drawn almost directly sideways while the elbows remain extended; however, once the arms reach a width equal to or greater than shoulder width, the elbows begin to flex. In this regard, the first part of the arm movement is very similar to the first part of the butterfly pull, as the direction in which the arms push the water and the corresponding elbow flexion are nearly identical in both strokes (Counsilman, 1986, p. 153).

3.3.2.3. The Recovery

To return the hands to their initial position, the arms must be brought back under the chest. This movement involves the pectoralis major, the anterior deltoid, and the long head of the biceps brachii, all of which contribute to flexion of the shoulder joint. At the same time, elbow extension by the triceps brachii completes the release phase and allows the arms to return to an extended position (McLeod, 2012, p. 6).

According to Maglischo (2003, p. 236), arm recovery should begin when the hands pass inward beneath the shoulders. At this moment, swimmers should stop pushing backward against the water and draw the arms downward and inward under the shoulders.

The swimmer presses the elbows downward and inward as soon as recovery begins. This helps facilitate the change in direction of the arms, which shift from inward to forward. The palms, which were turning inward during the previous sweep, continue rotating until they face each other when the hands meet under the chin. They then rotate downward into pronation as the arms extend forward.

Some swimmers prefer to recover their arms above the water, while others keep them underwater. It is not possible to state with certainty that those who recover above the water encounter less drag resistance. All swimmers using this method generate some drag. It remains to be determined whether the wave resistance they produce is less than the drag resistance created by underwater recovery.

Swimmers who recover underwater must strive to streamline their arms as much as possible when extending them forward. This can be achieved by keeping the arms close together and bringing the hands together to form a spearhead shape. The arms should recover just below the water surface. A recovery that is too deep would create greater drag and could also result in time loss due to the need to raise the hands during the next outsweep.

3.3.3. Leg Action

Swimming regulations stipulate that all leg movements must be simultaneous and in the same horizontal plane, without alternating motion. The feet must be turned outward during the propulsive phase of the leg action. Alternating movements or downward butterfly kicks are not permitted (World Aquatics. Rules, 2023-2025).

Leg action in this stroke has evolved from a wide, circular, snapping kick to a shorter, sharper, whip-like kick. Initially, the whip kick was thought to be superior because water could be pushed backward by extending the feet and using the soles as paddles.

Today, however, it is understood that the feet, like the hands, generate propulsion through circular movements. The leg kick currently used by most breaststroke swimmers is therefore a combination of the snapping and whip styles. Swimmers spread and bring their legs together, but only moderately, no longer separating them as widely as those who used the snapping kick (Costill et al., 1994, p. 101).

The laxity of the ankle joint and the degree of flexibility of the hip and knee joints particularly stressed in this stroke largely determine the effectiveness of the movement (Catteau & Garoff, 1986, p. 215).

3.3.3.1. Recovery

After the end of the propulsive phase of the arm movement, the heels are brought toward the buttocks in a vertical plane. The knees sink slightly to allow the heels to return. The knees move apart without exceeding shoulder width. Care should be taken not to bring the knees toward the abdomen (Pedroletti, 2000, p. 144).

The legs move forward because flexion occurs at the knees rather than at the hips. The legs are relatively narrow and therefore displace much less water forward during recovery.

In contrast, the thighs are much wider. If swimmers push them downward and forward (by flexing the hips) during recovery, the resulting braking effect would be so great that swimmers would almost come to a complete stop. Swimmers must allow their hips to drop and incline the body downward from head to feet in order to recover without flexing the hips. This is the only way to keep the feet underwater, which may be the main reason many elite breaststroke swimmers lift their head and shoulders out of the water.

The swimmers’ toes are pointed backward (feet extended), and the legs remain close together during recovery. The legs should be streamlined within the hip line throughout recovery to reduce form drag. The feet move almost directly forward rather than upward and forward. The knees separate slightly to keep the legs and feet within the body’s profile, but they must not move far beyond shoulder width.

The swimmer’s forward speed reaches its lowest point during the recovery phase. For this reason, the legs should be lifted quickly but smoothly. The feet should begin to separate as they approach the buttocks, marking the beginning of the next phase: the outsweep (Costill et al., 1994, pp. 101–102).

3.3.3.2. The Outsweep

The outsweep begins with the rotation of the feet outward, produced by a combination of movements at the hips, knees, and ankles. Once the feet are rotated outward, the outsweep continues with extension of the hips and knees. The gluteal muscles and hamstrings extend the hips, while the rectus femoris and quadriceps extend the knees (McLeod, 2012, p. 6).

This phase of the kick is not propulsive. Its purpose is to position the swimmer's feet for the following propulsive insweep. At this point, the swimmer begins to move the feet outward in a circular motion as they approach the buttocks. This movement continues until the feet are outside the hips, turned backward against the water. This position represents the catch position.

The lower limbs are flexed at the knees as much as possible so that they pass close to the buttocks. This allows a higher position and a longer insweep. The feet should be plantar-flexed and externally rotated at the ankle just before the catch. A large range of ankle mobility in these planes is a decisive advantage in breaststroke, as it allows swimmers to position their feet to push water backward earlier during the kick.

Swimmers should slightly flex the hips during the outsweep. Although this seems to contradict earlier statements, it does not. Hip flexion must be minimized during recovery but slightly increased during the outsweep to allow maximal force production during the following insweep. While hip flexion increases drag, it increases propulsive force even more by enabling activation of the thigh and leg extensors during the subsequent sweep.

Foot speed should decrease during the outsweep, reaching a velocity close to that of the body at the moment of the catch. The propulsive phase begins at this point (Costill et al., 1994, p. 102).

3.3.3.3. The Insweep

During the transition from the outsweep to the insweep, the knees and hips are not yet fully extended, and the respective muscle groups continue to contribute to the insweep until full extension is achieved. At the beginning of the insweep, the legs are in an abducted position that allows rapid adduction force production. The legs are brought together by contraction of the adductors located on the upper inner thigh.

To minimize resistance at the end of the insweep, the calf muscles act to point the foot and ankle. The release phase involves activation of the rectus femoris and iliopsoas for hip flexion, and the hamstrings for knee flexion (McLeod, 2012, p. 6).

The insweep consists of two phases. The first could be more accurately described as a downward sweep, as the feet move more downward than inward. Only during the final part do the feet move inward. This phase is described as a single movement in two parts because swimmers perceive it as a continuous leg sweep.

The insweep begins at the catch and continues until the legs are fully extended and nearly together behind the swimmer. It is a semi-circular movement in which the legs move outward, backward, downward, and finally inward. The hips and knees must extend until full extension is reached at the end of the movement. The feet should be oriented downward and inward until the soles face each other.

The feet should be oriented outward and slightly downward during the downward sweep corresponding to the first part of the movement. In this position, the leading edge of the foot is the big toe side, and the trailing edge is the little toe side. The first part of the insweep continues until the legs are extended. This is the main propulsive phase.

As the legs extend, foot orientation shifts from downward to inward, marking the second part of the insweep. The feet move through the water until they come together. The insweep ends just before the feet touch. At this point, the swimmer releases pressure on the water and begins to lift the legs toward the surface.

In this position, the big toe side continues to function as the leading edge of the propeller formed by the foot, while the little toe side remains the trailing edge. This combination of direction and angle of attack enables the swimmer to push water backward as it crosses the foot from leading to trailing edge. The foot must remain plantar-flexed so that the toes point downward, and the sole should be oriented inward rather than upward.

The swimmer’s hips will undulate slightly if the insweep is executed correctly. This occurs because the legs move downward as much as inward. The downward movement produces drag force that lifts the hips. Swimmers should not attempt to eliminate this slight undulation, as doing so would require sacrificing part of the propulsive force.

Foot speed should increase progressively throughout the insweep, reaching a peak just before pressure on the water is released (Maglischo, 2003, pp. 233–234).

3.3.4. Arm–Leg Coordination

Breaststroke is a simultaneous stroke in which the actions of both the upper and lower limbs are propulsive while alternately creating resistance to forward motion. Overall efficiency depends on motor continuity and thus on general coordination. Several coordination patterns can be observed among elite swimmers; however, the most important associations between arm phases and leg phases follow biomechanically logical principles (Chollet, 1997, pp. 126–127).

A breaststroke cycle can be represented as consisting of three arm phases and three leg phases (propulsion, recovery, glide). The recovery phases of both arms and legs are considered negative because they create significant resistance opposing forward motion. Expert coordination therefore involves synchronizing the recovery phases of both limb systems to reduce the duration of negative phases. This first part of the cycle thus corresponds to in-phase coordination of the recoveries.

Conversely, propulsion of one limb system is a positive phase and should occur while the other system is in a neutral (hydrodynamic) position, with the limbs extended (glide phase, neither negative nor positive). This second part of the cycle therefore corresponds to antiphase coordination of propulsion, ensuring propulsive continuity over two phases, while a third phase is devoted to recovery (Seifert & Chollet, 2007, p. 57).

According to Costill et al. (1994, p. 102), three synchronization styles are recommended by swimming experts: continuous, gliding, and overlapping. In the continuous style, arm movement begins when the legs come together. In the gliding style, a short interval exists between the end of the kick and the start of the arm movement, during which the swimmer glides passively. In the overlapping style, arm movement begins before the propulsive phase of the kick is completed.

Most coaches agree that the gliding style is the least effective, as swimmers decelerate from the end of the kick's propulsive phase until the start of arm propulsion. Advocates of the continuous style believe it eliminates the interval between force application by the arms and legs. However, this reasoning is flawed because the outsweep phase of the arm movement is not propulsive. Consequently, swimmers using the continuous style still decelerate between the end of the kick's propulsive phase and the moment they reach the arm catch.

The overlapping method is the best technique for eliminating or at least reducing the deceleration period between arm and leg propulsive phases. Swimmers should therefore begin the arm outsweep while the legs are completing the final part of the insweep. This allows them to reach the arm catch and begin propulsion almost immediately after the kick's propulsive phase ends.

3.3.5. Breathing

The symmetry of the stroke results in symmetrical head positioning. The spatial position of head elevation at the end of the arm insweep and the anatomical position of the rib cage at that moment logically determine the placement of inhalation during each of these phases (Chollet, 1997, p. 127).

According to Pelayo and Wojciechowski (1991, p. 30), in breaststroke inhalation occurs every cycle but is actually imposed by the regulatory requirement that the head must be submerged during each arm cycle.

In breaststroke, one breathing cycle is generally linked to one movement cycle. Since the arms remain continuously in the water, the head and trunk are permanently supported. As a result, the head remains more stable than in butterfly, facilitating breathing. During the pull phase, exhalation occurs underwater. In the next phase, when the arms press inward and downward, the upper body is slightly lifted, the mouth rises above the surface, and inhalation can be performed quickly and deeply.

Inhalation during this phase is facilitated by the relaxed state of the respiratory system, while the legs are positioned in preparation for their working phase (Lewin, 1981, p. 91).

Swimmers should look downward, with the head positioned between the arms as they extend forward, just before beginning the arm movement. They should begin lifting the head toward the surface as the arms start the outsweep. This is crucial, because if they delay head movement until the catch, much of the force from the initial part of the insweep will be used to lift the head rather than to propel the body.

In such a case, swimmers would need to turn their palms downward during the first part of the insweep to lift the head out of the water, sacrificing propulsive force and reducing forward speed.

The head must be at the surface at the moment of the catch. Subsequently, the downward arm movement facilitates face elevation so that the mouth emerges from the water as the arms release pressure and begin recovery. The swimmer should inhale during the arm recovery phase. The head should return underwater between the arms during the final part of this movement (Costill et al., 1994, p. 105).

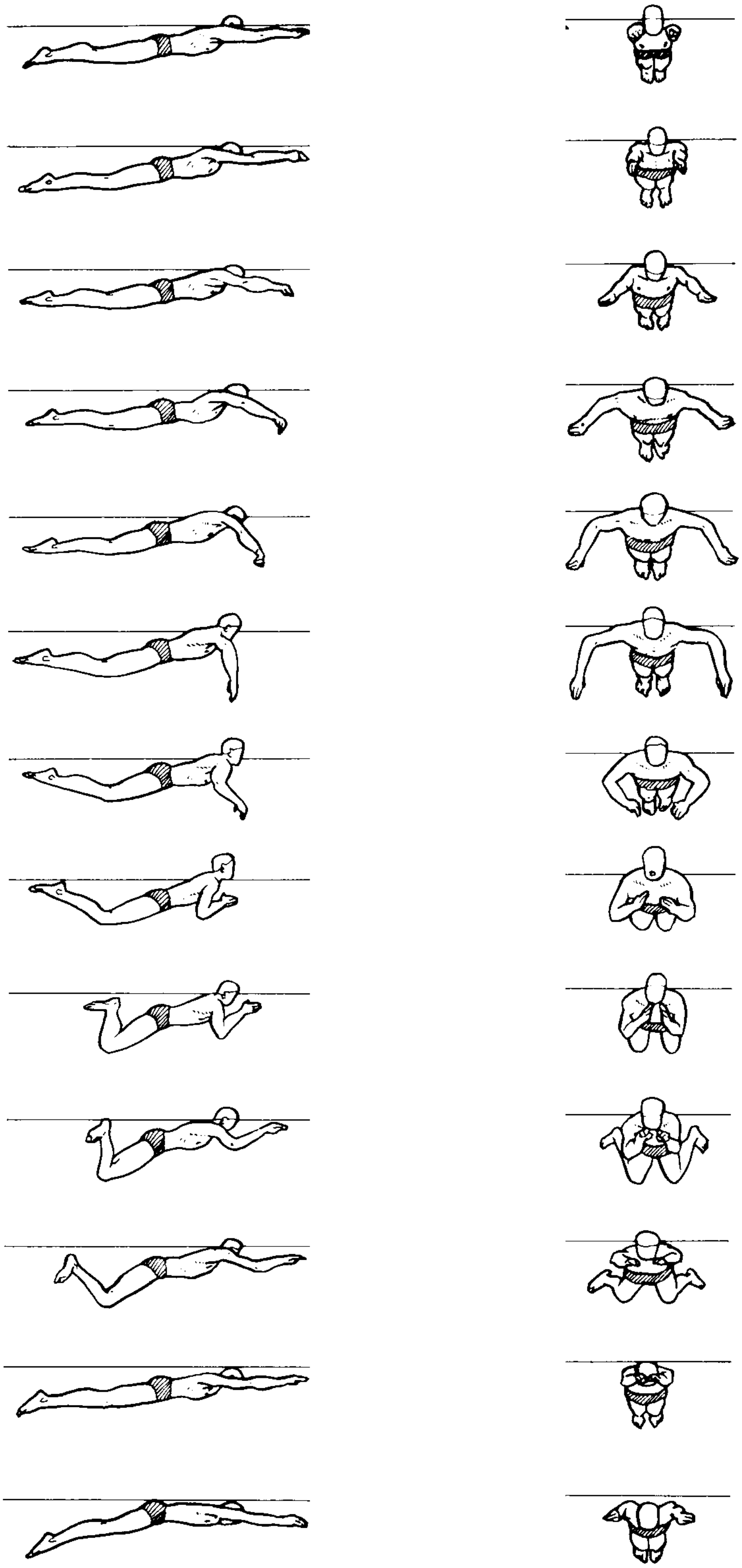

Figure 3: Illustration of Breaststroke Technique

3.4 Butterfly Stroke

During this stroke, both arms recover over the water while the legs kick simultaneously upward and downward in a dolphin or fish-tail motion. Two leg kicks must be performed for each arm cycle, and the swimmer must constantly keep in mind that the rules require the arm movements to be simultaneous and symmetrical on both sides. The same applies to the leg movements (Counsilman, 1986, p. 134).

3.4.1. Body Position

Due to the wave-like undulation of the body in the water and the simultaneous forward movement of both arms, body position in butterfly is less stable than in other strokes. This also modifies the degree of inclination of the (imaginary) transverse axis of the body relative to the water surface. It is important that this inclination remains significant and that the legs do not emerge from the water during the dolphin movements (Lewin, 1981, p. 87).

During the propulsive actions of the arms, body position must not hinder forward motion. Conversely, during the undulatory phases, body obliquity is not a disadvantage. Indeed, the frontal surface area is evaluated relative to the direction of movement, and in this case, since the displacement is oblique, the body must follow this direction in order to reduce drag. The head should streamline as much as possible during propulsive actions and must also anticipate respiratory movements. It rises toward the end of the arm push and returns to position before the second part of the arm recovery (Chollet, 1997, p. 118).

3.4.2. Arm Movement

Arm movement in butterfly consists of three diagonal sweeps and a recovery. The sweeps include the outward sweep, which comprises water entry and the catch, the inward sweep, and the upward sweep.

3.4.2.1. Outward Sweep, Water Entry, and Catch

The swimmer’s hands should enter the water in front of the shoulders, aligned with or slightly outside them. The palms should be turned outward so that the hands enter the water edge-first. After entry, the hands sweep outward and downward until they reach shoulder level laterally, with the palms facing backward; this is where the catch occurs and where the arms begin to produce propulsion.

The hands may be slightly turned outward or downward at the start of this sweep. However, regardless of their initial orientation, the palms must be turned outward during the outward sweep until they are oriented backward and outward at the moment of the catch. Hand speed decreases and is almost zero at the moment of the catch.

This outward sweep is not propulsive. It should be a smooth, stretching movement whose purpose is to position the hands correctly for the subsequent inward sweep, which is propulsive.

Swimmers should gradually flex their arms as they approach the catch position to facilitate backward orientation. Any attempt to apply propulsive force before the hands and arms are oriented backward and aligned in this manner will only result in a loss of speed by displacing water outward or downward (Maglischo, 2003, pp. 155–157).

3.4.2.2. Inward Sweep

The inward sweep is the first of the two propulsive sweeps in butterfly. The arms sweep downward, inward, and upward in a semi-circular motion, while the elbows continue to flex after the catch. The inward sweep ends when the two arms nearly touch beneath the swimmer's body. At this point, the arms are flexed at approximately 90 degrees.

The hands, which were oriented outward and backward at the catch, are progressively turned inward during this phase, finishing oriented inward and upward when they meet beneath the swimmer. Hand speed increases moderately throughout this movement (Counsilman, 1986, p. 157).

Throughout the propulsive phase, the pectoralis major and latissimus dorsi are the primary driving muscles, while the wrist flexors maintain the wrist in a neutral to slightly flexed position. The biceps brachii and brachialis are activated to move the elbow from full extension at the initiation of the catch to a flexed position of about 40 degrees during the intermediate part of the pull (McLeod, 2012, p. 4).

3.4.2.3. Upward Sweep

The upward sweep begins when the hands come together at the end of the previous sweep. They describe a circular path outward and backward and then sweep upward toward the water surface. The hands quickly rotate outward so that they are oriented outward and backward during this upward sweep.

Hand speed decreases during the transition between the inward and upward sweeps, then accelerates until pressure is released at the water surface. This release occurs around thigh level, at which point recovery begins. The swimmer's arms extend slightly during the upward sweep but remain somewhat flexed until the beginning of the release phase (Costill et al., 1994, p. 81).

Unlike freestyle, butterfly swimmers forcefully extend their elbows during the final part of the pull, thus engaging the triceps brachii to a much greater extent. As in freestyle, the rotator cuff and deltoid muscles act during the recovery phase, but the mechanism differs slightly. In butterfly, there is no body roll to assist recovery as in freestyle; instead, trunk undulation lifts the upper body out of the water and contributes to the recovery process.

Once again, the scapular stabilizer muscles are extremely important, as they provide a solid anchoring point for the propulsive forces generated by the arms and assist in repositioning them during recovery (McLeod, 2012, p. 4).

3.4.2.4. Release and Recovery

At the end of the arm push, the hands are located slightly beneath or just outside the thighs. The whipping action of the hands has no propulsive function; it reflects a change in hand trajectory and marks the beginning of recovery. Arm exit occurs at thigh level.

Simultaneous aerial recovery is only possible with full extension of the upper limbs, and relaxation is essential. For effective relaxation, only the muscles responsible for projecting the arms forward should be contracted. When this occurs, the palms face upward. This pronated position of the laterally extended arms skimming the water tends to be maintained throughout the recovery path. However, due to the requirement for relaxation, once the arms pass beyond shoulder alignment, the hands tend to rotate so that the palms face downward.

Depending on the degree of laxity of the swimmer’s shoulder joint, the range of motion achieved as the arms pass overhead may vary (Catteau & Garoff, 1986, p. 186).

Although there is no body roll in butterfly as in freestyle, trunk stabilizer muscles are crucial for linking upper and lower limb movements and play an essential role in the undulatory motion that allows the swimmer to lift the upper trunk and arms out of the water during recovery. This movement is produced by the contraction of the paraspinal muscles, which run in groups from the lower back to the base of the skull. This contraction arches the back while the arms are in the recovery phase. Abdominal muscle contraction follows rapidly, preparing the upper body to re-enter the water after the hands and initiate the next propulsive phase (McLeod, 2012, p. 4).

The arms, which were slowly extended during the upward sweep, are rapidly extended after release so that they leave the water in a circular motion directed upward, outward, and forward. They then travel over the water until the next entry. The arms may be fully extended or slightly flexed during the first half of recovery. It is recommended that swimmers slightly flex their arms during the second half of recovery to facilitate the transition between water entry and the outward sweep.

During the final phase of recovery, the arms are oriented more inward, but their direction must change outward after water entry. This change is facilitated if the arms are slightly flexed before entering the water, as they can then be extended after entry, causing the hands to move outward even while the arms are still moving inward.

The hands should remain on the sides during recovery, oriented inward during the first half and outward during the second. Recovery should be fast but not abrupt. Swimmers must allow sufficient time to position their legs for the downward phase of the first kick before the arms enter the water. The arms should remain as relaxed as possible so that the muscles can recover during this phase. Swimmers should allow the momentum from the upward sweep to carry their arms during the first half of recovery and use only minimal energy during the second half to redirect the arms forward and re-enter the water.

Although recovery is performed relatively low and laterally, the arms must rise sufficiently to avoid contacting the water and creating wave drag. Swimmers must lift their shoulders well out of the water to create adequate clearance for the arms during aerial recovery (Costill et al., 1994, pp. 81–83).

3.4.3. Dolphin Kick

According to the latest swimming regulations, all upward and downward movements of the feet must be simultaneous. The legs or feet do not have to be at the same level, but they must not alternate. A breaststroke kick is not permitted (World Aquatics Rules, 2023-2025).

The dolphin kick describes the leg movement in butterfly because the legs move together like a dolphin’s tail, whose horizontal fin produces propulsion through vertical movements. The upward and downward pivoting of the hips and nearly closed legs produces continuous propulsion in humans in a similar manner. The impulse for the dolphin movement originates in the thoracic and lumbar vertebrae and is transmitted through the pelvis, thighs, ankles, feet, and finally the toes. Because propulsion involves both hip and leg movements, it is not appropriate to refer solely to leg movements (Lewin, 1981, pp. 87–88).

The dolphin kick used at the start of the race and after each tumble turn engages a larger muscle mass than the smaller, more isolated leg kicks associated with arm movements. In addition to hip and knee motion, the dolphin kick incorporates trunk undulation by engaging trunk stabilizers and paraspinal muscles (McLeod, 2012, p. 4).

3.4.3.1. Upward Kick

Like the flutter kick in freestyle, the butterfly kick is a whipping movement in which one kick begins as the other is nearly completed. It begins with the legs almost extended during the downward phase of the previous kick. The downward kick produces a rebound effect that drives the swimmer’s thighs upward. After completing the downward kick, the legs continue to glide upward, extending until they reach hip level. The next downward kick begins at this point.

The action of lifting the legs is performed by the hip extensors, primarily the gluteus maximus muscles. Water pressure above the legs maintains them in extension during the upward kick and also pushes the feet into a natural position midway between flexion and extension. Swimmers should not bend their knees during this upward kick (Maglischo, 2003, p. 161).

Posterior muscles, particularly the gluteus maximus and hamstrings, ensure elevation of the lower limbs. As the water load above the legs decreases, hamstring activity produces a slight, involuntary knee flexion. The feet, kept in plantar flexion from the start of this phase, reach or exceed the surface at the highest point of the kick. This elevation of the legs results in a slight sinking of the hips, with the pelvis serving as a pivot point (Catteau & Garoff, 1986, p. 192).

3.4.3.2. Downward Kick

The downward phase of the first kick, which is the largest of each cycle, is a whipping action that begins with hip flexion, continues with knee extension, and ends with ankle flexion. This kick begins as the swimmer's feet pass above body level. At this stage, the swimmer presses downward with the thighs. Water pressure, now acting from below upward, causes the legs to flex and the feet to rise into a position of plantar flexion and inversion. Shortly after the hips begin to descend, the swimmer forcefully extends the legs to complete the downward kick (Costill et al., 1994, p. 84).

The release phase of the kick is driven by the gluteal muscle group. Simultaneous contraction of the hamstrings contributes to hip extension. The foot is maintained in plantar flexion through the combined effect of water resistance and activation of the gastrocnemius and soleus muscles (McLeod, 2012, p. 4).

3.4.4. Arm–Leg Coordination

Over a complete arm cycle, two undulations occur, each consisting of an upward and a downward phase. Optimal coordination precisely links a leg undulation phase with a key arm phase.

The downward phase of the first kick occurs when the arms enter the water after aerial recovery. The downward phase of the second kick occurs during the second part of the underwater propulsive arm movement, namely during the push. During this latter phase, the hands tend to push the hips downward. The second kick is therefore executed so that its downward phase prevents the hips from being pulled downward.

The second kick of the cycle appears slightly more pronounced than the first, especially when the butterfly swimmer is moving at maximum speed. However, at slower speeds, the first kick tends to be more pronounced than the second (Counsilman, 1986, p. 143).

3.4.5. Breathing

Due to the symmetry and simultaneity of motor actions in butterfly, breathing logic in this stroke is also symmetrical. Because the head is submerged during swimming balance, a voluntary and well-coordinated movement is required to bring the head into an optimal breathing position. As in other strokes, there should be as little conflict as possible between fixing the rib cage to optimize arm propulsion and allowing chest mobility for inspiration.

The most advantageous spatial position for head elevation is linked to the arm push and the second leg undulation. Taking these two factors into account, the swimmer must anticipate head positioning by gradually lifting it from the end of the pull. The head is fully raised, with the chin brought forward during the arm push and the downward phase of the leg undulation. This positioning allows inspiration to occur. Expiration, particularly when breathing every arm cycle, must be coordinated with inspiration to avoid respiratory pauses (Chollet, 1997, pp. 119–120).

Immediately after inhalation, the head lowers and quickly re-enters the water. When expiration does not begin immediately, it is usually for mechanical rather than physiological reasons. The simultaneous movement, which requires more power than alternating movements, demands a solid anchoring point on the rib cage for the arm muscles. A brief inspiratory apnea provides this support and occurs at the beginning of the pull (Catteau & Garoff, 1986, p. 194).

In butterfly, breathing every two cycles is the most commonly used pattern, although swimmers often switch to breathing every cycle at the end of 200 m races. Underwater observation of expiration reveals that it is rarely continuous and is often short and explosive following apnea during pulling phases, particularly in simultaneous strokes (Pelayo & Wojciechowski, 1991, p. 30).

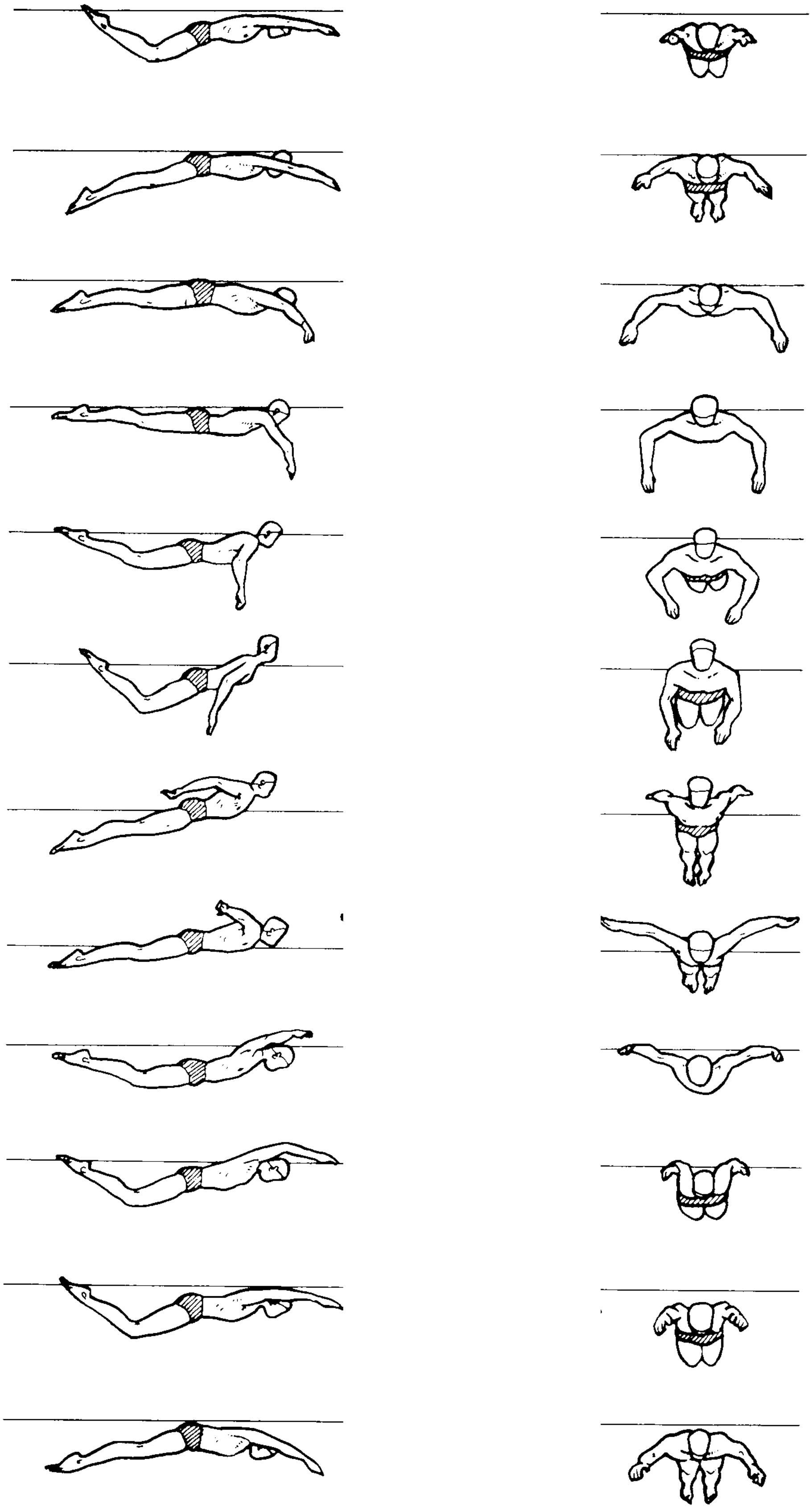

Figure. 4: Illustration of the Butterfly Stroke Technique

3.4.6 Course Objectives

General Objectives

By the end of these four courses, students will be able to:

- Understand the biomechanical, physiological, and technical foundations of competitive swimming strokes
- Analyze swimming techniques using scientific and observational criteria
- Master the technical execution of the four competitive strokes according to international regulations
- Identify common technical errors and propose appropriate corrective exercises
- Apply principles of coordination, propulsion, resistance reduction, and breathing
- Integrate swimming techniques into teaching, coaching, and performance contexts
- Develop critical thinking based on scientific literature in swimming sciences

Specific Objectives by Stroke

Front Crawl (Freestyle)

Students will be able to:

- Describe and perform efficient body alignment and streamlining
- Analyze arm propulsion phases and flutter kick mechanics
- Coordinate breathing with arm and leg actions
- Apply hydrodynamic principles to minimize drag
- Teach front crawl technique at beginner and intermediate levels

Backstroke

Students will be able to:

- Maintain stable horizontal body position in supine swimming
- Execute symmetrical arm actions with continuous propulsion
- Coordinate backstroke kick with arm recovery
- Control breathing rhythm without visual reference
- Identify postural and coordination errors specific to backstroke

Breaststroke

Students will be able to:

- Understand the simultaneous and cyclic nature of breaststroke movements
- Analyze the propulsive phases of the arm pull and leg kick
- Respect official rules governing breaststroke technique
- Optimize glide phases and stroke timing
- Teach breaststroke progression from basic to advanced levels

Butterfly

Students will be able to:

- Explain body undulation and dolphin kick mechanics
- Analyze arm propulsion phases and aerial recovery
- Coordinate two leg kicks per arm cycle
- Integrate breathing without disrupting propulsion
- Identify muscular involvement and energy demands specific to butterfly

3.4.7 Evaluation Methods

Evaluation is conducted according to continuous assessment principles and aligns with the LMD system.

Evaluation Components

Component	Description	Weight
Written Examination	Theoretical knowledge: biomechanics, technique, rules, terminology	40%
Practical Assessment	Technical execution of the four strokes	30%
Continuous Assessment	Attendance, participation, drills, skill progression	20%
Mini-Project / Assignment	Technical analysis, video analysis, or teaching plan	10%

Evaluation Criteria

- Accuracy of technical execution
- Quality of coordination and timing
- Respect of swimming regulations (FINA rules)
- Ability to analyze and correct technique
- Use of appropriate scientific terminology

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Chapter 4: Swimming Starts and Turns

Introduction

Starts and turns are fundamental aspects of competitive swimming that significantly influence overall race performance. These techniques allow swimmers to maximize propulsion, minimize time loss at the walls, and maintain momentum across strokes like freestyle, backstroke, breaststroke, and butterfly.

Effective starts and turns can account for up to 10-20% of total race time in shorter events, making them critical for elite and developmental athletes alike. Mastering them enhances hydrodynamic efficiency and reduces drag during entry and exit phases. For adolescent swimmers, early training in these skills supports technique refinement and injury prevention.

There are two primary starts: the grab start, where both feet are positioned on the block edge for a balanced push, and the track start, with one foot forward on a raised pedal for greater explosive power. The grab start enables rapid activation, while the track start optimizes forward drive, particularly in sprint events. Swimmers may fully submerge up to 15 meters post-start, fully extending the body underwater.

Turns fall into hand-touch (open) turns for breaststroke and backstroke, and tumble turns (culbutes) for freestyle and butterfly, which involve a forward somersault for faster wall contact and push-off. Transitional turns in medley relays combine elements for stroke changes. Proper execution prioritizes a tight streamline position off the wall to glide efficiently.

4.1 Starts

The International Swimming Rules determine the style or method that the swimmer must follow. Article 4 of the rules confirms that in the starts for freestyle, breaststroke, butterfly, individual medley, and freestyle relay, swimmers must dive from the starting block upon hearing the starting signal.

When swimmers hear the long whistle from the referee, they must all step onto the starting blocks and remain there until they hear the command from the starter (“Take your marks”). At this moment, swimmers must assume the starting position by placing one foot on the front edge of the starting block or both feet together, and the starter gives the starting signal after ensuring that all swimmers are motionless in their positions. (World Aquatics. Rules, 2023-2025).

4.1.1 Phases of the Start from the Starting Block

4.1.1.1 Two-Foot Start (Conventional Start – Grab Start)

Figure. 01: Grab Start (Two-Foot Start)

4.1.1.1.1 Ready Position Phase

This is the most commonly used method among swimmers. The swimmer stands with both feet on the front edge of the starting block, with the toes gripping the edge from the outside. The distance between the feet is preferably shoulder-width, although this varies among swimmers due to differences in body characteristics.

The hands grip the front edge of the block and may be placed either outside or between the feet. The knees are flexed at an angle between 30 and 40 degrees, the head is lowered between the arms, the gaze is directed toward the water below the block, and the swimmer concentrates on hearing the starting signal.

This technique allows for a longer flight distance in the air and a nearly vertical water entry, with the hands entering first, followed by the head, trunk, and legs, forming as small a circle as possible. This reduces resistance caused by water impact and contributes to a deeper entry and smoother underwater glide. However, this method is slower in leaving the starting block compared to the track start.

4.1.1.1.2 Pull Phase

Upon hearing the starting signal, the swimmer pulls the hips upward, allowing the center of mass to move forward and downward beyond the front edge of the block. At this moment, the swimmer feels as if they are about to fall into the water.

The swimmer then extends the legs at the hip and knee joints, which further enhances the forward fall toward the water. This position forces the swimmer to begin leaving the starting block.

4.1.1.1.3 Push-Off Phase

This phase begins when the swimmer leaves the starting block, immediately after the body moves forward and downward due to the sensation of falling. At this moment, the knee extension angle reaches approximately 80 degrees, and the legs are extended.

The force generated by extending the hip and knee joints directly contributes to the propulsive force of the feet and ankles against the starting block. After the hands release the block edge, the arms extend rapidly forward in a nearly semicircular path until they reach beneath the chin. The head moves in coordination with the arms until the toes leave the block, at which point the swimmer looks downward.

The swimmer leaves the block forming an angle between the extended legs and the surface of the starting block ranging between 40 and 50 degrees, depending on the swimmer’s characteristics, pushing ability, and swimming stroke.

4.1.1.1.4 Flight Phase

After leaving the starting block, the swimmer’s body is fully extended in the air. When the swimmer’s midsection (waist) reaches its highest point, the swimmer begins to snap the legs upward while the head moves downward between the arms, preparing for water entry in as small a circle as possible.

4.1.1.1.5 Entry Phase

The swimmer must enter the water through the opening created by the hands, following a streamlined line as much as possible, with the arms fully extended together above the upper part of the head. Entry begins with the fingertips, followed by the arms, head, trunk, legs, and finally the feet, with the toes fully extended backward.

The entry angle ranges between 30 and 40 degrees relative to the water surface. This angle varies depending on the stroke: breaststroke swimmers prefer a deeper entry to allow for a longer pull, while freestyle swimmers prefer a quicker return to the surface. Therefore, freestyle swimmers perform fast downward dolphin kicks to help surface more quickly.

4.1.1.1.6 Glide Phase

After entering the water, the swimmer should glide in a streamlined position for a short duration, especially in short-distance events. The body must remain straight, avoiding excessive arching at the waist, which delays speed.

The swimmer should not wait until speed decreases, as this requires additional effort to reaccelerate. Therefore, the swimmer must determine when to begin leg kicks to support the glide in freestyle and butterfly, and when to initiate the arm pull in breaststroke.

4.1.1.1.7 Pull-Out Phase (Surfacing)

Freestyle and butterfly swimmers prefer to begin dolphin kicks at the start of the glide, performing 2 to 4 kicks, depending on individual technique, as the allowed underwater distance is up to 15 meters. These kicks are sufficient to bring the swimmer to the surface, provided they are performed while maintaining streamlining.

For freestyle swimmers, the first arm pull helps bring the swimmer to the surface. Alternating leg kicks should begin with the arm pull and continue until the swimmer surfaces. Breathing should be avoided upon surfacing; instead, it is recommended to delay breathing until one or more full arm cycles are completed.

Butterfly swimmers should continue dolphin kicks even when initiating the arm pull with both arms and should avoid breathing upon surfacing.

Breaststroke swimmers, after completing the first arm pull and beginning the second, should raise the head before the pull is completed. Breaststroke swimmers are allowed to inhale during head emergence and then continue swimming.

4.1.1.2 Alternating Foot Start (Track Start)

Figure. 02: Track Start

4.1.1.2.1 Ready Position Phase

This modern technique is widely used and resembles the sprint start in athletics. The swimmer places one foot at the front edge of the block and the other foot behind, similar to a track athlete's starting position. Both hands grip the front edge of the block.

The swimmer trains to position the center of mass over the rear leg. This technique is well suited for explosive starts.

It allows for a faster takeoff due to quicker forward transfer of the center of mass and shorter time to water entry, though with a shorter flight distance. Propulsion occurs sequentially—first from the rear leg, then from the front leg. However, this method may cause slight time loss due to a sharper entry angle, increasing impact resistance with the water.

4.1.1.2.2 Pull Phase

At the starting signal, the swimmer pulls the hands forward and downward, causing the body to lean forward and downward. The rear leg extends first, immediately followed by the front leg. Simultaneously, the arms move forward and upward in a semicircular path until reaching the optimal entry position.

4.1.1.2.3 Push-Off Phase

The swimmer pushes first with the rear leg, followed by the front leg, focusing on transferring the center of mass forward. The arms snap forward and upward beneath the chin while the front foot continues pushing against the front edge of the block until the leg is almost fully extended.

4.1.1.2.4 Flight Phase

After leaving the block, the swimmer travels through the air in a nearly straight line. This does not require a high jump or excessive arching, but rather an angle that allows linear flight. When the waist reaches its highest point, the swimmer snaps the legs upward and moves the arms and head downward between the arms.

4.1.1.2.5 Entry Phase

Water entry is similar to the two-foot start. The swimmer should enter the water at nearly one point, with the hands overlapping, followed by the forearms, head, trunk, legs, and fully extended feet. The entry angle is smaller than in the conventional start, which helps freestyle sprinters avoid deep entry.

4.1.1.2.6 Glide Phase

After entry, the swimmer decides when to begin dolphin kicks in freestyle and butterfly to maintain streamlining. In freestyle, after one dolphin kick (depending on technique), the swimmer may perform 2 to 4 alternating leg kicks before surfacing.

4.1.1.2.7 Pull-Out Phase

Before reaching the surface, the swimmer initiates the pull with the dominant (leading) arm while maintaining a straight trajectory. After completing the pull, the head breaks the surface. Breathing should be avoided during at least the first full arm cycle after surfacing.

4.1.2 Start from the Water (Backstroke Start)

According to international swimming rules, backstroke and medley relay events begin from the water. Swimmers enter the pool at the first long whistle. At the second whistle, swimmers move to the wall beneath the starting block. After swimmers take their positions, the starter gives the command “Take your marks,” and once all swimmers are motionless with toes on the wall, the starting signal is given.

4.1.2.1 Ready Position Phase

The swimmer faces the wall, gripping the starting handles beneath the block with both hands. The feet are placed on or below the water surface against the wall, with toes touching the wall and heels away from it. The legs and hips are inclined in the water.

At the command “Take your marks,” the swimmer bends the elbows and pulls the trunk upward into a crouched position. The head is lowered between the arms, with the chin touching the upper chest. The hips, legs, and heels are brought closer together. Some swimmers use one-leg support, others both legs; research has not shown significant performance differences.

4.1.2.2 Push-Off Phase

At the starting signal, the swimmer throws the head upward and backward, eyes facing the wall. The trunk is pushed upward and backward by pulling on the handles, followed by rapid release of the hands and snapping them overhead. Simultaneously, the legs extend at the knees and ankles, pushing forcefully against the wall with the toes, generating backward propulsion.

4.1.2.3 Flight Phase

The swimmer’s body travels through the air in an arched trajectory. The arms are extended overhead, and the head is positioned backward beneath the arms. Although foot entry causes resistance, a higher takeoff angle and good back arch reduce this resistance.

4.1.2.4 Entry Phase

The swimmer enters the water in a straight line: hands first, followed by arms, head between the arms, trunk, and extended legs. The swimmer attempts to create a narrow opening in the water with the hands and head. Because the trunk is close to the surface during flight, the hips usually enter smoothly behind the head. Maintaining leg extension reduces impact resistance.

4.1.2.5 Glide and Leg Kicks Phase

Upon water entry, the swimmer snaps both legs downward to align the body for underwater glide. Dolphin kicks are then performed to approach race speed, up to 15 meters. Typically, 3 to 6 dolphin kicks are recommended. If the swimmer is weak in underwater dolphin kicking, alternating kicks (2–4) may be used instead.

4.1.2.6 Pull-Out Phase

The swimmer initiates the arm pull at the appropriate time to surface smoothly. After completing the pull, the swimmer establishes the backstroke rhythm while maintaining a streamlined body position near the surface.

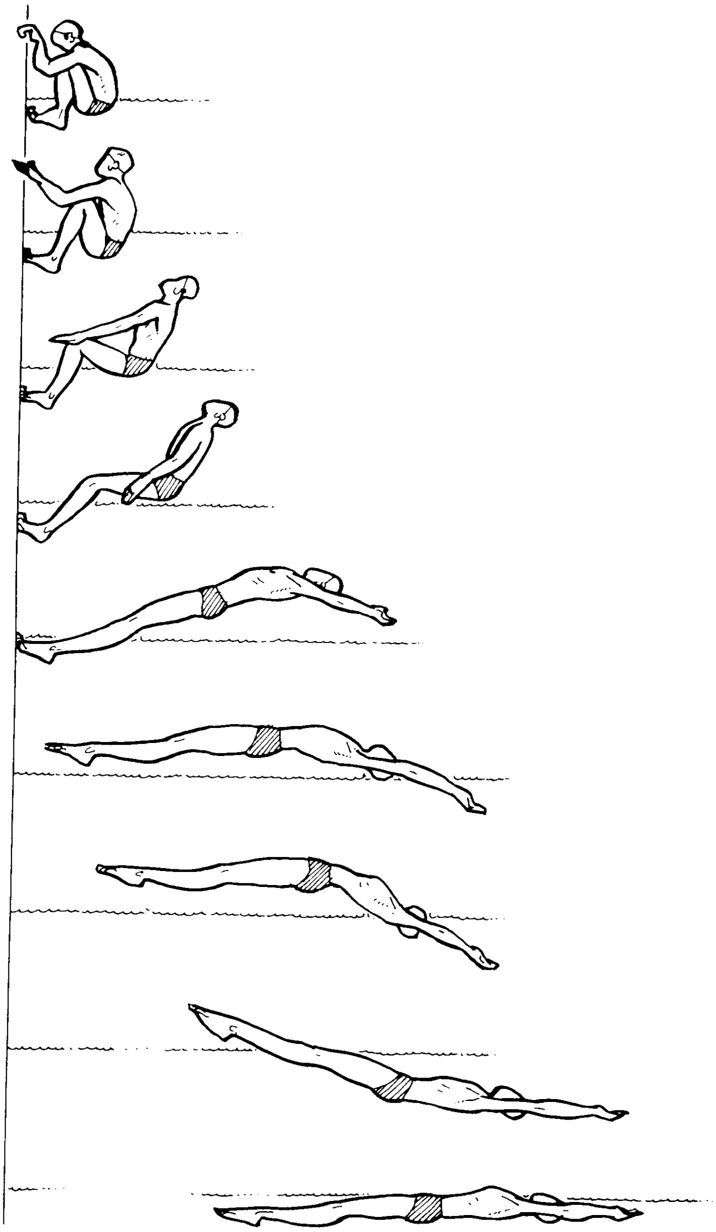

Figure. 03: Backstroke Start

4.2. Turns in the Four Swimming Strokes

4.2.1. Turn in Freestyle Swimming

The freestyle turn can be divided into the following phases:

4.2.1.1. Approach Phase

This phase begins approximately 5 meters before the pool wall, a distance indicated by the red lane markers on both sides of the pool. During this phase, the swimmer must maintain forward speed without deceleration, as higher speed allows for a faster and more efficient turn.

The final arm stroke is usually performed at a distance of approximately 1.7 to 2.0 meters from the wall, depending on the swimmer's anthropometric characteristics, technical proficiency, and race distance.

4.2.1.2. Rotation Phase (Flip Turn)

This phase begins when the first arm completes its pull toward the hip. The swimmer tucks the chin toward the upper chest while the opposite arm finishes its push phase. At this moment, the swimmer pulls the knees toward the abdomen, preparing for the somersault rotation.

During the rotation, both arms remain close to the body, with the hands positioned near the hips. At the end of the rotation, the palms face downward, and the swimmer presses the hands downward to assist in lifting the head toward the water surface. The head remains positioned between the arms while the feet search for and contact the wall.

At the end of this phase, the swimmer rotates around the longitudinal axis until reaching a lateral body position. The speed of rotation should be as high as possible.

4.2.1.3. Push-Off Phase

This phase begins when the swimmer's feet make contact with the wall at a depth of approximately 30 to 40 cm below the water surface. The swimmer then extends the legs and pushes explosively against the wall.

The push-off is executed while the body is in a lateral position, with the arms extending forward. The body then returns to a horizontal position, marking the beginning of the glide phase. A powerful push-off is essential to achieve a streamlined position and an effective glide.

4.2.1.4. Glide Phase

This phase begins immediately after the push-off. The swimmer's body is horizontal, streamlined, and fully extended underwater, with the arms stretched forward above the head, the legs extended backward, and the toes pointed. The hands are placed one on top of the other, preferably with the pulling arm's hand underneath.

The glide continues until the swimmer approaches optimal forward speed. Depending on race distance and technique, underwater dolphin kicks may be used to maintain momentum.

4.2.1.5. Pull-Out and Surfacing Phase

This phase begins when the swimmer feels close to the appropriate forward speed and approaches the water surface. Alternating leg kicks are used to assist in surfacing. The swimmer initiates the pull with the stronger arm, followed by the second arm.

Breathing should be avoided during the first complete arm cycle upon surfacing to minimize hydrodynamic resistance and maintain a horizontal body position.

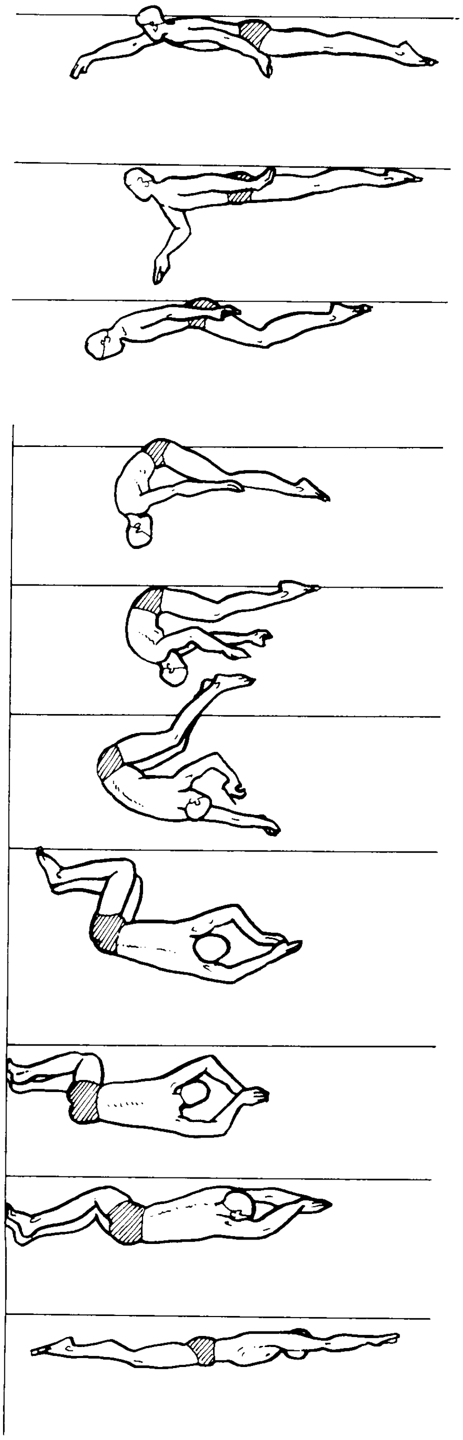

Figure. 04: Freestyle Turn

4.2.2. Turn in Backstroke Swimming

Recent updates to international swimming regulations allow backstroke swimmers to perform underwater dolphin kicks up to 15 meters after the turn. Swimmers are also permitted to rotate from a back position to a breast position before initiating the turn, provided that no arm or leg movements occur except those directly related to the flip turn. The swimmer must return to a back position before leaving the wall.

To assist swimmers in judging the distance to the wall, flags are placed 5 meters from the wall across the width of the pool.

4.2.2.1. Approach Phase

This phase begins approximately 5 meters from the wall. In modern backstroke turns, the swimmer uses the final two arm strokes to prepare for the turn. When the first of these strokes enters the water, the swimmer rotates the body around the longitudinal axis from a back position toward a breast position.

During this transition, the first arm continues its pull while the opposite arm completes its recovery above the water. No leg kicks are permitted during the transition phase.

4.2.2.2. Rotation Phase

When the second hand enters the water, the swimmer initiates the forward somersault. The chin is tucked toward the chest, resulting in spinal flexion. At this moment, leg movement becomes permitted, and a dolphin kick is recommended to raise the hips and accelerate rotation.

4.2.2.3. Push-Off Phase

At the completion of the rotation, the hands are positioned above the head, and the feet are placed firmly against the wall. The swimmer then extends the legs explosively to push off the wall.

The arms are extended forward with one hand placed over the other, and the swimmer must return to a back position before leaving the wall. The push-off angle should be slightly downward to facilitate an effective glide.

4.2.2.4. Glide Phase

After leaving the wall, the swimmer maintains a horizontal, streamlined back position underwater. Dolphin kicks may be used during this phase, provided that the distance does not exceed 15 meters. Toward the end of the glide, the body angle gradually directs the swimmer toward the water surface.

4.2.2.5. Undulation, Pull, and Surfacing Phase

As the swimmer approaches optimal forward speed near the surface, alternating leg kicks are used to assist in surfacing. The swimmer initiates the pull with the stronger arm, followed by the second arm.

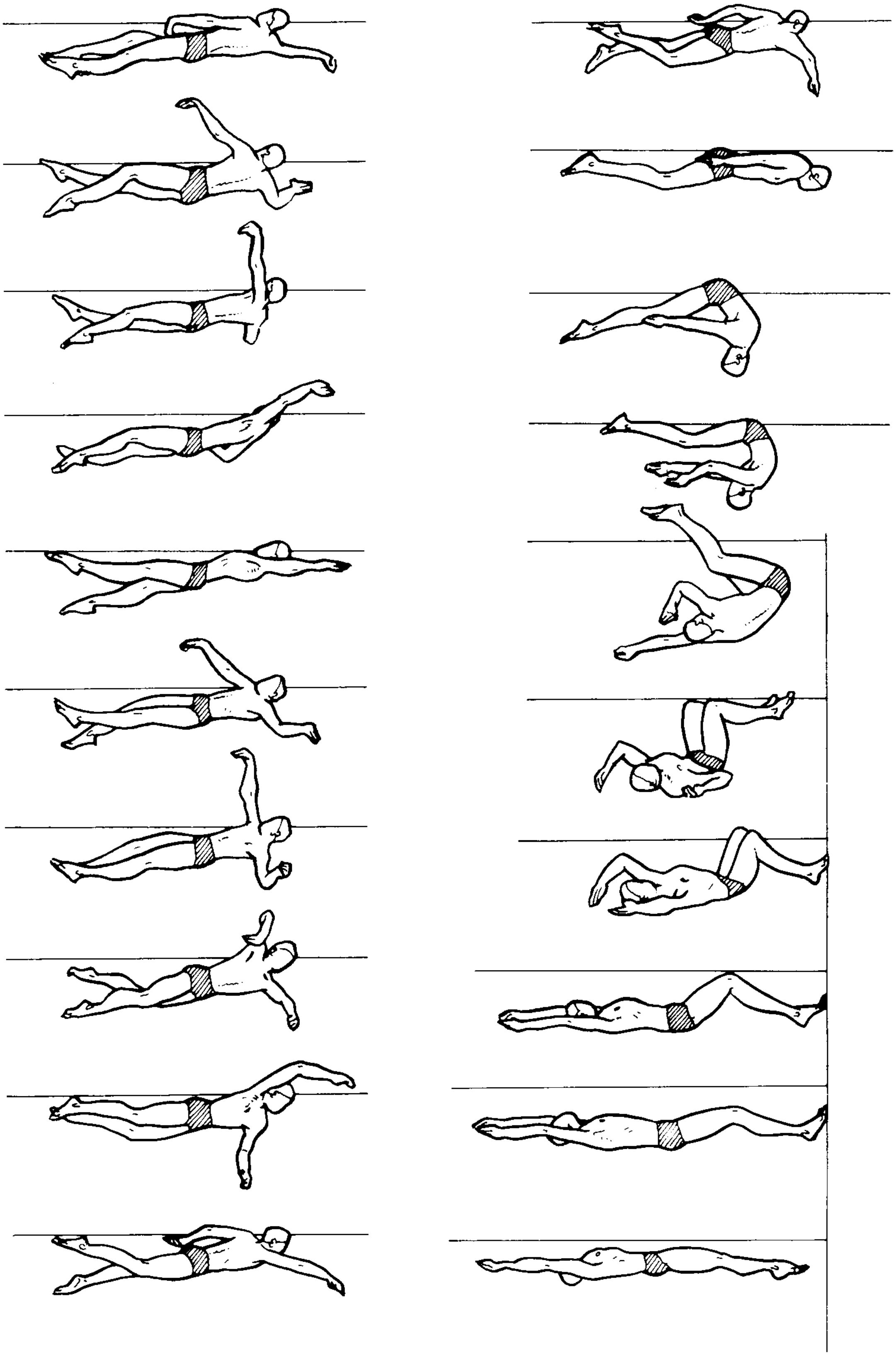

Figure. 05: Backstroke Turn

4.2.3. Turn in Breaststroke and Butterfly Swimming

The turns in breaststroke and butterfly follow a similar sequence from approach to glide.

4.2.3.1. Approach Phase

This phase begins during the final 5 meters before the wall, identified by red lane markers. The swimmer must maintain speed and accurately judge the number of arm strokes required to reach the wall.

The swimmer must touch the wall with both hands simultaneously, either above or below the water surface, with the shoulders level and parallel to the water surface.

4.2.3.2. Rotation Phase

This phase begins after the two-hand touch. The swimmer immediately releases one hand and directs it downward and backward underwater while extending the elbow. Simultaneously, the knees are drawn toward the abdomen, and the feet search for the wall.

4.2.3.3. Push-Off Phase

At the beginning of this phase, the body is positioned nearly sideways, with the feet planted on the wall and the knees flexed. The hands come together, the head is positioned between the arms, and the swimmer pushes explosively off the wall.

The push-off angle differs between strokes: breaststroke swimmers push off at a downward angle, whereas butterfly swimmers aim for a more horizontal angle. The swimmer must achieve a fully streamlined position at the end of the push-off.

4.2.3.4. Glide and Surfacing Phase

The swimmer glides in a streamlined position until approaching optimal forward speed. Butterfly swimmers initiate underwater dolphin kicks while respecting the 15-meter limit and continue kicking during the first arm pull. Breathing should be delayed upon surfacing.

In butterfly events:

- **50 m and 100 m**: breathing is recommended after two or more arm cycles.
- **200 m**: breathing may occur after one complete arm cycle.

Breaststroke swimmers perform a full underwater arm pull followed by one complete leg kick. During the second arm pull, the head emerges before the completion of the pull, allowing inhalation before continuing surface swimming.

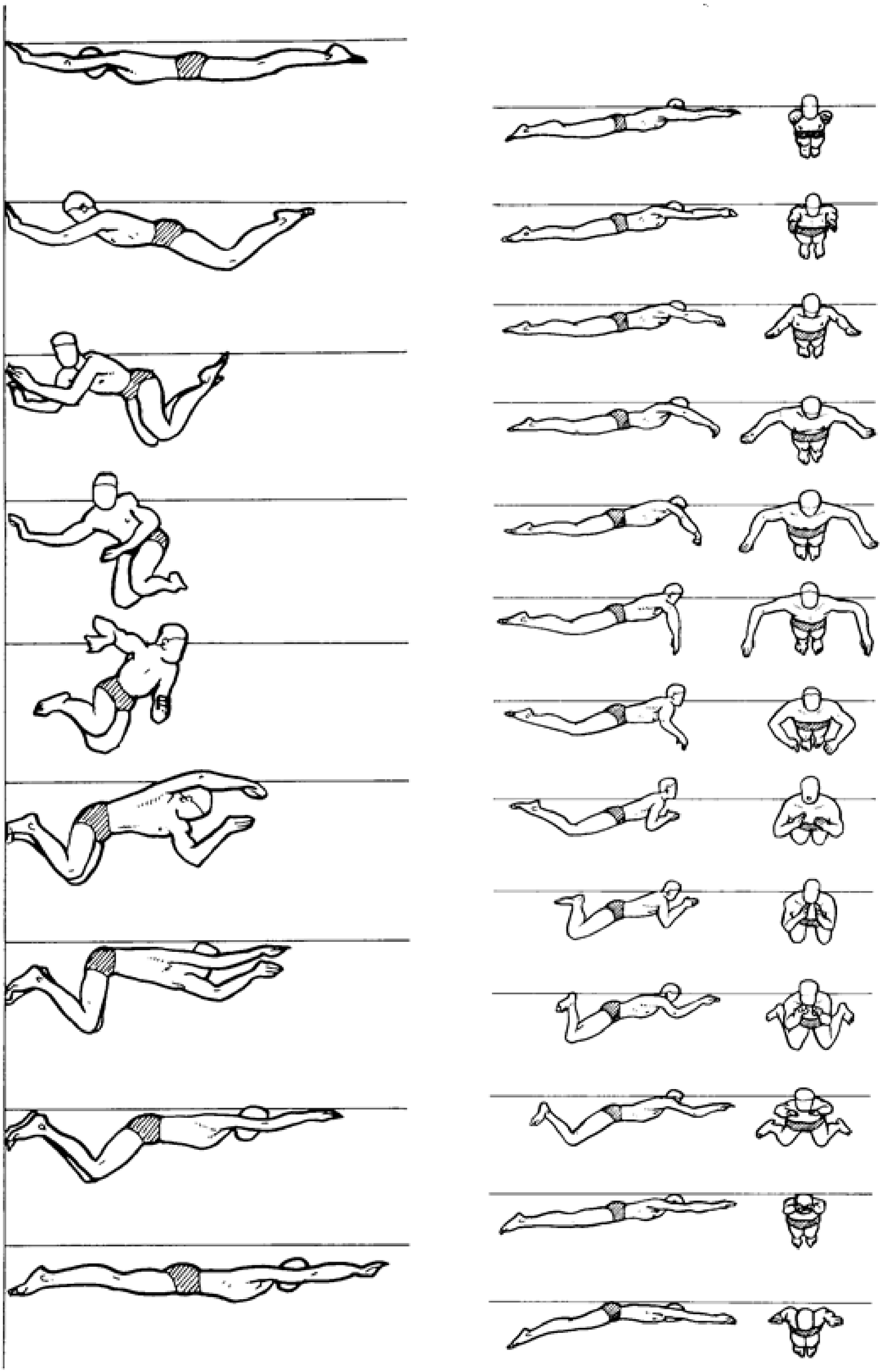

Figure. 06: Breaststroke and Butterfly Turn

4.3 Course Objectives

At the end of this course, students will be able to:

4.3.1 General Objectives

- Understand the biomechanical, technical, and regulatory principles governing competitive swimming.
- Master the technical execution of the four competitive swimming strokes and their associated starts and turns.
- Apply scientific principles (biomechanics, physiology, and motor learning) to improve swimming performance.
- Analyze and correct technical errors using observation and basic video analysis.
- Develop the ability to teach, demonstrate, and evaluate swimming techniques in an educational or coaching context.

4.3.2 Specific Objectives

- Explain the phases of starts (block start and backstroke start) and their performance determinants.
- Describe and apply correct techniques for freestyle, backstroke, breaststroke, and butterfly.
- Execute and analyze turns according to FINA regulations.
- Optimize streamlining, propulsion, and underwater phases.
- Respect international swimming rules related to starts, turns, and underwater distance.
- Design simple technical drills for skill improvement.

4.4 Evaluation Methods

Evaluation is conducted according to the LMD system, combining continuous assessment and final examination.

- Continuous Assessment (40%)

- **Practical skill assessment (20%)**
    - Execution of swimming strokes
    - Starts and turns performance
    - Streamlining and underwater techniques
- **Continuous practical tests (10%)**
    - Technical drills
    - Skill progression
- **Participation and attendance (10%)**
    - Active engagement during practical sessions
    - Correct use of technical terminology

- Final Examination (60%)

- **Written Examination (30%)**
    - Short and long-answer questions
    - Technical analysis of swimming movements
    - Rules and biomechanics of swimming
- **Practical Examination (30%)**
    - Demonstration of:
        - One competitive start
        - One turn
        - Two swimming strokes
    - Evaluation criteria:
        - Technical accuracy
        - Coordination
        - Efficiency and body alignment

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Digital & Teaching Resources

World Aquatics (FINA) Educational Resources

- Technical manuals
- Coaching clinics materials

Human Kinetics Online Learning Platform

- Video analysis resources
- Teaching aids for swimming instruction

Chapter 5: Stages of Swimmer Development

Introduction

Sports practice increasingly shows that maximum athletic performance can only be achieved if the necessary foundations have been acquired during childhood and adolescence. This requires a systematic long-term training program. The main challenge is to structure long-term programming as a coherent process, divided into time-limited stages, emphasizing specific content, to move from a general, versatile sports education to specialized training in a specific discipline.

For long-term training programming, decisive elements are: on one hand, programming the evolution of performance over time, and on the other hand, defining the necessary stages based on the age of maximum performance and the general conditions for long-term preparation for achieving peak performance. (Weineck, 1997, p. 43)

According to Schmitt (1997, p. 205), the goal is to store "at the right time" a maximum number of basic programs in the early years of life, which will serve as a foundation for subsequent developmental stages. Children should be given the opportunity to experience and encode thousands of varied balances, jumps, runs, throws, and spins. Storing these thousands of mini-programs, sometimes very complex, provides a frame of reference and allows the child to choose the mini-program best suited to the situation. Conversely, if the child is not exposed early to rich and varied situations, they are likely to be incapable of performing complex motor activities as adults.

It also appears dangerous not to respect the stages of nervous system development, as the harmonious development of higher cortical functions depends on the proper completion of earlier stages. According to Cazorla (1993) and authors inspired by his work, in swimming, five stages seem to best cover the long maturation required to hope to reach the highest level, provided the swimmer has the will and capabilities.

5.1 Preparatory Stage or Initiation (Beginner)

Age: 7–10 years

This is a basic preparation phase, during which the child should be exposed to the maximum variety of activities, situations, and motor learning, allowing them to acquire the main motor skills necessary for future sports practice, or simply for harmonious psychomotor development. During this period, using playful activities, the child must feel comfortable in the aquatic environment, correctly acquire the four swimming techniques, and develop an interest in competitive swimming. (Cazorla, 1993, p. 15)

According to Weineck (1997), this stage corresponds to the first school age. Children at this age are exuberant, and this behavior returns to normal only toward the end of the period. One expression of this passionate need for movement is enthusiasm for sport, making it the period with the highest sports club enrollment.

Other characteristics of this period:

- Good psychological balance, optimism, carefree attitude, enthusiastic assimilation of knowledge and motor skills, lack of critical thinking.
- Favorable morphology: small, light, slim, and tall children with good leverage for strength.
- Improved concentration compared to earlier stages, finer motor differentiation, and more precise information processing.

The first school age is already an excellent period for learning. Although the ability to acquire new motor sequences is highly developed, memory consolidation is limited. The predominance of emotional processes and the widespread activation of central nervous system command processes easily lead to confusion between different motor loops, making memorization difficult. Newly learned elements must therefore be repeated frequently to be permanently integrated into the child's repertoire. (Weineck, 1997, pp. 83–84)

Training Recommendations:

- Start training around 7–8 years old.
- 2–3 hours per week, divided into 2–3 sessions.
- Gradually increase swimming distance: 300 km in the first year, progressing to 500 km by the end of this stage.
- Focus on basic endurance and harmonious development of all muscle groups. (Scelles et al., 1987, p. 17)

Psychophysical dispositions favorable for motor skill acquisition, repertoire expansion, and coordination improvement should be exploited. Multi-sport training is a priority. In disciplines requiring early technical formation, techniques should already be refined. The child's enthusiasm should also be used to develop attitudes and habits that encourage lifelong sports participation. (Weineck, 1997, p. 85)

Objectives: Develop basic physical qualities: agility, speed, flexibility, endurance, coordination. Training includes gymnastics, athletics, team sports in addition to swimming, with group learning and games.

- Annual sessions: 100–160
- Weekly sessions: 3–4
- Annual swimming distance: 300–500 km (Verger, 1993, p. 173)

5.2 Beginning of Structured Training

Age: 10–12 years

Continuing from the previous stage, this is the transitional period. According to Weineck (1997, p. 85), it is generally considered "the best age to learn." Differences from the previous stage are gradual. Growth, improved load-to-strength ratio, proportion harmony, and increased strength allow children to achieve significant physical mastery.

By age 10–11, the vestibular system and other sensory factors reach near-adult maturity, allowing children to acquire and master relatively complex movements requiring spatial-temporal orientation.

Key Points:

- High need for activity, audacity, and risk-taking, favoring motor skill development.
- What is missed at this age must be compensated for later with far greater effort.
- Acquisition of basic and possibly advanced sports techniques.
- Movements must be precisely learned to avoid re-learning later. (Weineck, 1997, p. 85)

Training Focus:

- Playful activity continues.
- Consolidation of interest in swimming, improvement of the four techniques, and gradual increase in training volume.
- Physical priorities: aerobic endurance, gestural speed, joint amplitude.
- Training remains versatile; no specialization yet. Participation in competitions is encouraged to maintain motivation. (Scelles et al., 1987, p. 17)

Program Example (Cazorla, 1993; Verger, 1993):

- Group training emphasizing team spirit.
- Specific preparation: 60% swimming, muscle strengthening, flexibility exercises.
- Learning sports hygiene: sleep, rest, nutrition, perseverance.
- Annual sessions: 180–270
- Weekly sessions: 4–5
- Annual swimming distance: 600–900 km
- Strength training: 90–120 hours

Talent detection begins, along with maintaining good academic performance.

5.3 Beginning of Specialization

Age: 11–13 years (girls), 12–14 years (boys) – First phase of puberty

The beginning of specialization corresponds to the first phase of puberty, the second morphological transformation. It starts around 11–12 years for girls and 12–13 years for boys, lasting respectively until 12–13 and 14–15 years.

Characteristics:

- Rapid physical changes: appearance of sexual characteristics, disappearance of infant structures, dramatic changes in body proportions, with height increases up to 10 cm and weight up to 9.5 kg per year.
- Psychological disturbance caused by hormonal instability.
- Decrease in specialized coordination due to altered strength-to-weight ratio.
- Less precise motor control; typical aberrant movements.

Training Considerations:

- First phase of puberty allows maximal trainability of physical condition factors.
- Training should focus primarily on physical capacity improvement, while gradually stabilizing and enhancing coordination abilities.
- Increased intellectual capacity allows for new forms of motor learning and general training programming.
- Adolescents' broader expectations require more personalized training, greater participation in programming, and variety in training methods (learning, exercises, games).
- Load must consider fluctuating motivation. Improper training (too hard, too unilateral) is a common reason many adolescents quit sports, even when they could develop optimally. (Weineck, 1997, pp. 85–86)

At this stage, children enter an age of contradictions, combining intensive training, performance goals, and self-doubt. The adolescence transformation disrupts movement precision. (Binder, 1998, p. 10)

Individualization:

- Training increasingly individualized according to life and study conditions.
- Morphological, psychological, physical, and physiological traits become clearer at 13–14 years.
- Aerobic capacity development is favorable, justifying increased training volume and intensity.
- Peak improvement usually occurs between 13 and 15 years. (Cazorla, 1993, p. 15)

Training Focus:

- Improvement of swimming techniques through specific exercises.
- Mixed group and individualized training.
- Specific preparation: 70% swimming.
- Development of competitiveness and psychological resilience.

Program Example (Verger, 1993):

- Annual sessions: 400–500
- Weekly sessions: 5–8
- Strength training hours: 120–150

5.4 High Specialization

Age: 15–17 years – Second phase of puberty (adolescence)

High specialization marks the final stage of development, from childhood to adulthood. Growth slows, body proportions harmonize, improving coordination. Strength and motor pattern acquisition conditions are optimal for performance enhancement.

Key Points:

- Adolescence allows simultaneous maximal development of physical condition and coordination, making this period ideal for overall motor performance improvement.
- Most difficult movements are learned faster and retained better.
- Psychophysical capacity allows heavier and more intense training loads. (Weineck, 1997, pp. 86–87)

Training Process:

- Continued individualization and specialization to maximize training effectiveness.
- Training previously focused on aerobic metabolism now diversified:
    - Aerobic work: 70%
    - Mixed work: 15%
    - Anaerobic lactate and alactate work: 6%
    - Recovery work: 9%

Additional Considerations:

- Medical and paramedical care integral to prevent overtraining and optimize recovery. (Cazorla, 1993, p. 16)
- Systematic testing ensures load regulation for each individual.
- Psychological education developed to improve motivation, resilience, ambition, and emotional control.

Program Example (Verger, 1993):

- Annual sessions: 480–600
- Strength training hours: 150–200

5.5 Elite Level or Maturation

Age: 17 years and above

At this stage, the swimmer has reached sufficient maturation to potentially achieve international level performance. This stage reveals individual capacity for a high-level career, influenced by physical, psychological, and sociological factors. (Cazorla, 1993, p. 16)

Characteristics:

- Maximal performance often occurs at the end of adolescence, requiring adult-level training methods and content. (Weineck, 1997, p. 87)
- Focus on refining sport-specific techniques, physical capacities relevant to the discipline, and personal technical style.
- Individualized training: video analysis, tactical skill development, psychological optimization (motivation, concentration, emotional regulation).
- Broadening relational environment, controlling activity, managing emotional responses.

Program Example (Scelles et al., 1987; Cazorla, 1993):

- Annual sessions: 560–600
- Weekly sessions: 10–15
- Annual swimming distance: 1500–3600 km

5.6 Objectives

At the end of this course, students should be able to:

1. Understand the stages of swimmer development from childhood to elite performance.
2. Identify physiological, morphological, and psychological characteristics at each age and developmental phase.
3. Recognize the importance of training adaptation based on age, maturation, and individual traits.
4. Design age-appropriate training programs, including volume, intensity, and type of exercises.
5. Explain the role of individualization, specialization, and high-level preparation in achieving elite performance.
6. Integrate theoretical knowledge into practical coaching: planning sessions, evaluating progress, and optimizing swimmer development.

5.7 Evaluation Methods

To assess understanding and application of this course, several evaluation methods can be used:

Evaluation Type	Description	Weight Suggestions
Written Exam	Questions on stages, age ranges, characteristics, and training principles.	30–40%
Case Study / Program Design	Students create a long-term swimmer development program for a given age group.	30%
Practical Assessment	Observe and evaluate a swimmer's technical progress; recommend adjustments.	20%
Oral Presentation Discussion	Students explain the rationale for training plans and developmental decisions.	10–20%
Participation Engagement	Attendance, contribution to group discussions, peer feedback.	10%

Example Evaluation Questions:

1. Explain the key characteristics of the preparatory stage (7–10 years) and suggest appropriate training methods.
2. Compare the training focus of early specialization (11–14 years) versus high specialization (15–17 years).
3. Design a weekly swimming program for a 12-year-old transitioning from basic skills to early specialization.

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