

Effect of a Six-week Dry-land Resistance Training on Swimming Endurance and Speed of Swimmers in Lead City International School, Ibadan, Nigeria

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in the Department of Kinesiology, Sports Science and Health Education, Faculty of Arts and Education, Lead City University, Ibadan, Oyo State for the award of Master Degree (M.Sc. (Ed) in Exercise Physiology, Lead City International School Ibadan, Oyo State, Nigeria.

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Certification

This is to certify that Adebimpe Rukayat OLALERE with matriculation number LCU/PG/001365 carried out this research work titled “Effects of a 6-week Dry-Land Resistance Training on Swimming Endurance and Speed of Swimmers in Lead City International School Ibadan, Oyo State, Nigeria” in the Department of Kinesiology, Sports Science and Health Education, Faculty of Arts and Education, Lead City University, Ibadan, Oyo State for the award of Master Degree (M.Sc. (Ed) in Exercise Physiology and that this has not been previously submitted.

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Dedication

This thesis is dedicated to God Almighty and to people who have supported me throughout my education. Thanks for making me see this adventure through to the end.

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This research work was conducted in Lead City University, Ibadan, Oyo State and all of the data for analysis were collected in Lead City International School, Ibadan, Oyo State, Nigeria.

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Abstract

Swimming performance is a diverse activity combining energy, kinetic, motor control, anthropometrics, and swimming strength. When discussing the demands of speed and endurance, dry-land resistance training must be considered. The use of dry land training for swimmers has received little to no attention in several Nigerian researches. Therefore, this study interest was to examine the effects of a 6-week dry-land resistance training on swimming endurance and speed of swimmers in Lead City International School Ibadan. Pretest-posttest control group experimental research design using matched participants with a 2x2 factorial matrix was adopted for this study. Fifty-two swimmers of Lead City International School were selected to take part in the study. The participants were assigned into control group (26) and experimental group (26). Experimental group were made to go through six weeks dry-land resistance training programme, while the control group were made to undergo 20 minutes of benefits of exercise lesson for six weeks. Data were collected before and after the intervention programme. Data was analyzed using both descriptive and inferential statistics. The descriptive statistics used were frequency count and percentages, while Analysis of Co-variance (ANCOVA) was the inferential statistics used to determine the main as well as the interaction effects of the independent, dependent and moderating variables. There was a significant main effect of treatment on swimming endurance ($F_{(1,49)}=102.087, p<0.05, \eta^2=0.676$) of swimmers in Lead City International School, Ibadan. There was also a significant main effect of treatment on swimming speed ($F_{(1,49)}=37.096, p<0.05, \eta^2=0.431$) of Lead City International School swimmers, Ibadan. There was no significant main effect of sex on swimming endurance. Resistance training on dry-land improved swimmers' swimming abilities. Therefore, it was suggested that coaches be taught on the advantages of adopting dry-land training to enhance swimming performance.

Keywords: Swimming Speed, Swimming Endurance, Dry-land training, Resistance training, Swimming events

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List of Acronyms

Abbreviation	Meaning
LCIS	Lead City International School
MAD	Measuring Active Drag
VO ₂	Oxygen Consumption
RPE	Rating of Perceived Exertion
LIT	High Intensity Training
HR	Heart Rate
HVT	High Volume Training
MIT	Modulated Intensity Training
HIT	High Intensity Training
ANS	Autonomic Nerve System
CG	Control Group
SI	Swimming Intensity
LTAD	Long-Term Athlete Development
ASA	Amateur Swimming Association
YPD	Youth Physical Development
ATP	Adenosine Triphosphate
AMP	Adenosine Monophosphate
CaMK	Calcium-Calmodulin Kinases
GAS	General Adaptation Syndrome
P	Performance
T	Time

USRPT	Ultra-Short Race-Pace Training
SR	Stroke Rate
AOD	Accumulated Oxygen Deficit
SV	Swimming Velocity
FD	Drag Force
FP	Propulsive Force
AMP	Activated Protein Kinase
HIT	High Intensity Training
OT	Overtraining Syndrome
SL	Swimming Length
PRQ	Physical Readiness Questionnaire
SPSS	Statistical Package Social Sciences Software

Chapter One

Introduction

1.1 Background to the Study

Swimming is an individual or team sport that involves moving through water using one's body.¹ The sport may be done in a pool or in open water such as sea or lake. Swimming is characterized by the repetition of a certain bodily action or swimming stroke in order to push the body ahead.¹ There are several strokes, each of which defines a distinct swimming style or crawl. Front crawl, breaststroke, backstroke and butterfly are examples of swimming strokes. All main body components, including the torso, arms, legs, hands, feet and head, move in a rhythmic and synchronized manner throughout most strokes.¹

Endurance is one of the most important elements to be considered in a number of competitive sport². It is usually used in aerobic and anaerobic exercises because it is an essential prerequisite for swimming performance³. Endurance is the ability to perform mechanical work over a longer period of time, thus delaying the depletion of the energy supplies available in the muscle cells³. The body gradually diminishes the effects of the residual substances accumulated as a result of tissue metabolism, through the buffer systems and the mechanisms for the removal of effort-induced catabolites³. The improvement of endurance is linked with an increase of the number of mitochondria and the higher oxidative capacity of the muscles³.

Speed on the other hand is the distance travelled per unit of time. This is the rate at which an object is moving in an interval of time and this can be determined as the distance travelled by the object divided by the duration of the interval⁴. Swim speed is the rate at which a swimmer is able

to swim a given distance ⁴. Swimmers usually want to swim fast or swim more efficiently at some point. To swim fast means completing a set distance in less time⁵. Swimming more efficiently means completing a workout or a race distance in the same amount of time but at a lower energy cost. An increase in swimming speed requires a corresponding increase in the applied muscle force⁶. Swimming strokes necessitate different set of skills. The type of stroke or swimming event is one of the determinants of swimming performance. Generally, swimming performance can be influenced by the types of style adopted by the swimmer⁴. In most cases, the breast stroke and front crawl swimmers have shown improved level of performances when compared to their counterparts in the other two strokes. It has also been shown that differences exist in the performance of the swimmers across the four strokes in terms of techniques, energy cost and stroke length⁷. For different levels of athletes (national level, international level), the changes in the sex gap over time showed that the sex-related differential in swimming speed was bigger for freestyle than for breaststroke at race distances ranging from 50 m to 200 m for national swimmers, but not for international swimmers⁷.

Swimming is a low-impact aerobic activity, which attract the participation of all category of human being. Children as young as six months and adults in their seventy enjoy swimming especially in developed countries. In some developing countries swimming is gaining currency as swimming is included in many primary and post primary school curriculum and age group competitions are organized as observed by the researcher ¹. Since the foundation of the first modern Olympic Games in 1896, the sport of swimming has been a component of the Olympic events. There are 34 swimming events, with distances ranging from 50 to 10,000 meters, making swimming one of the most well-liked Olympic sports. At the 2016 Rio Olympics, winning times for Olympic gold medals ranged from 21.4 seconds for the 50-meter dash to 1 hour, 56 minutes,

and 32.1 seconds for the 10,000-meter competition. Swimming is one of the most popular Olympic sports, with 34 events covering distances of 50 to 10,000 meters. Olympic gold medal winning times ranged from 21.4 seconds for the 50-meter dash to 1 hour, 56 minutes, and 32.1 seconds for the 10,000-meter competition at the 2016 Rio Olympics. A median time of under two minutes and 20 seconds is required for 26 of the 34 swimming events at the Olympics, which are held over distances of 200 meters or less. Even though the majority of swimming competitions are short-lived, swimmers' training regimens frequently involve significant training volumes, such as the total distance or duration completed each session, week, or month, for instance. This form of instruction is used regularly by swimmers of all ages and abilities. Competitive swimmers also train far more regularly than athletes in other cyclical sports like running, rowing, cross-country skiing, and cycling. This is particularly true for young swimmers; whose weekly mean swimming training volumes range from 16 hours on average to 29 hours (or 110 km) on rare occasions.⁹

In competitive swimming the goal is to complete the race as fast as possible. For that purpose, an optimal interaction of several body components, such as energetic, kinematics, kinetic, motor control, anthropometrics, swimming strength and swimming power must occur¹⁰. Hence, in order to obtain high-performance results in swimming, there is need to review the training concepts taking into consideration the parallel approach of all training elements ¹¹. High-intensity resistance training changes athletes' physiological attributes in respect to aerobic power and anaerobic capacity¹². It is further opined that high-intensity resistance training simultaneously increases athletes' muscular endurance, hypertrophy, strength, and power¹³. Resistance exercises and body weight movements can help athletes become stronger, more flexible and better equipped to handle day-to-day feats of strength and athleticism that are often

overlooked¹⁴. Resistance training is prescribed across a variety of sports and is shown to improve swimming performance¹⁴.

Dry-land resistance training is the activity done on land with the intended purpose of increasing strength, flexibility and overall physical mobility. This includes a number of different movements and exercises ranging from beginner to advanced skill level. Some exercises that are commonly performed include pushups, sit-ups, squats, etc. In well-trained endurance athletes, dry-land resistance training can result in an improved capacity for both long- and short-term endurance¹⁶. Swimmers training need to include a wide range of resistance training because they require a good level of endurance whether they swim long distance or short. Power training as a type of dry-land resistance training has the potential to develop muscle strength under dynamic conditions. The demand of dry-land resistance training in addition to the aerobic and anaerobic in-water training have the potential of optimizing physical requirements of swimming which in turn influence the performance¹⁴. An increase in dry-land resistance training should translate to a stronger and more effective swimming skill performance¹⁸. In this regard, similar dry-land training exercises can improve force generation needed for a push off in swimming¹⁹.

The years of experience in swimming can be strongly correlated to the swimmer's performance. The higher the number of years spent by swimmers in practice and competition, the greater the level of achievement and the more comfortable they tend to be in the swimming pool. However, swimmers who have little training or competition experience tend to have less development of the required swimming skills for optimum performance²⁰. Therefore, this study will examine the effects of a 6-week dry-land resistance training on swimming endurance and speed of Lead City International School swimmers.

1.2 Statement of the Problem

Swimming performance necessitates swimmers covering the event distance in the quickest time possible, with race results determined by fractions of a second. The capacity of the swimmer to overcome the resistance of the water in an efficient way and generate successful start and turns can be related to variations in biomechanical, physiological, and anthropometric variables. Existing literature agrees that resistance training is a powerful and effective technique for improving swimming performance.

From the researcher's observations in the most recent inter-school friendly swimming competitions, the Lead City International School swimmers speeds in the first half of the swimming races are fast, however the speed typically decreased in the middle of the events. As a result, they sometimes failed to win medals at the conclusion of the swimming races. It was also observed that Lead City International School Swimmers focused on the use of repetitive swimming in the pool as their training method. The only land based activities engaged in during training sessions are light stretching before entering the pool which are not regular practices. The researcher is of the opinion that if the swimmers' speed and endurance could be improved, the chance that they will do better during competition is more likely. Previous studies focused more on strength training as a way of improving swimming performance. Findings revealed that combining swimming and dry-land strength training improves performance in different events more effectively than the swimming programme alone. On the other hand, previous studies paid minimal or no attention to the use of dry land training for athletes in swimming. As a way of

providing objective evidence as to the efficacy of dry-land training in enhancing performance in swimming, this study interest is to examine the effects of a 6-week dry-land resistance training on swimming endurance and speed of swimmers in Lead City International School Ibadan, Oyo State, Nigeria.

1.3 Aim and Objectives of the Study

The aim of this study was to investigate the effects of a 6-week dry-land resistance training programme on swimming endurance and speed of swimmers in Lead City International School, Ibadan. The specific objectives for this study are to:

1. access the resting heart rate of swimmers before and after six weeks in Lead City International School, Ibadan
2. determine the effect of a 6-week dry-land resistance training programme on swimming endurance of swimmers in Lead City International School, Ibadan
3. ascertain the effect of a 6-week dry-land resistance training programme on swimming speed of swimmers in Lead City International School, Ibadan
4. examine the effects of a 6-week dry-land resistance training programme on swimming endurance of the swimmers based on their sex.
5. access the effects of a 6-week dry-land resistance training programme on swimming speed of the swimmers based on their sex.
6. determine the interaction effect of treatment and swimming endurance of the swimmers

7. determine the interaction effect of treatment and swimming speed of the swimmers in Lead City International School.

1.4 Research Question

The following research question was answered in this study.

1. What is the resting heart rate of swimmers before and after six weeks Dry-land resistance training in Lead City International School, Ibadan?

1.5 Hypotheses

The following hypotheses were tested in this study:

1. There will be no significant main effect of treatment on swimming endurance of swimmers in Lead City International School, Ibadan following a 6-week Dry-land resistance training.
2. There will be no significant main effect of treatment on swimming speed of swimmers in Lead City International School, Ibadan following a 6-week Dry-land resistance training.
3. There will be no significant main effect of sex on swimming endurance of swimmers in Lead City International School, Ibadan following a 6-week Dry-land resistance training.
4. There will be no significant main effect of sex on swimming speed of the swimmers following a 6-week Dry-land resistance training.

5. There will be no interaction effect of treatment and sex on swimming endurance of the swimmers following a 6-week Dry-land resistance training.
6. There will be no interaction effect of treatment and sex on swimming speed of swimmers in Lead City International School, Ibadan following a 6-week Dry-land resistance training.

1.6 Significance of the Study

Findings from this study will reveal the effectiveness of dry-land resistance training programme on in-water swimming endurance and speed of the participants. The dry-land resistance training programme utilized in this study can serve as template which can be adopted by individual swimmers, teachers and swimming coaches for work-out to improve fitness and develop attributes needed for enhanced performance by athletes in swimming competitions.

Athletes in international swimming competition usually put in a lot of time in the pool to achieve minor improvements or marginal increases in their overall performance. An improvement in performance by 1% inside a competition (heats to finals) can make a swimmer to remain in contention for a medal. If a high-level competitive swimmer can reduce their total race time by more than 1% over the course of a year, they will be substantially more competitive in international events. This could be achieved using dry-land resistance training.

At the lower level of competitive swimming, athletes in educational institutions can benefit from this research in the sense that there would be an improved chance of the schools winning medals in any swimming competition the school may partake in by incorporating dry-land resistance training to their training schedule. Finally, this research will provide objective information that will add to existing knowledge and serve as basis future research in the subject matter.

1.7 Scope of the Study

This scope of this study focused on Dry-land resistance training as the independent variable, while Swimming endurance and Swimming speed were examined as dependent variables. The participants consisted 52 swimmers of Lead City International School, Ibadan. The swimmers were divided into two groups of 26 participants each assigned to dry-land resistance training

for experimental and benefits of exercise for control group. The intervention programme was conducted at the Lead City International School sport field and swimming pool. Equipment such as weighing scale, wrist watches, tape ruler, sphygmomanometer and stopwatch were used. Three (3) trained research assistants were involved in the conduct of the study which lasted six weeks.

1.8 Limitation of the Study

There are few cases of inconsistencies in training attendance by some participants as a result of instability in lecture time table and other commitments that sometimes kept them on and off the school since they are not camped. Also the researcher did not have adequate control over the diet of the participants since they were not camp for the study.

In addition, the researcher did not have total control over activities of participants on days of the week when there was no training

1.8 Operational Definition of Terms

Swimming: It is an individual or team racing sport that will require a participant to use one's entire body to move through water.

Swimming Endurance: The ability of the swimmer to keep exerting force against a resistance.

Swimming Speed: The time the participant will use to cover a distance in water over a short period of time.

Dry-land resistance Training: These are activities done on land with the intended purpose of increasing strength, flexibility and overall physical mobility using skipping ropes, medicine ball and exercise mat.

Swimming Strokes: These are the different swimming styles (Front crawl, Backstroke, Butterfly and Breast stroke) that are employed in the course of moving the body through water.

Resistance Training: It involves the performance of physical exercises which are designed to improve strength and endurance of the participant.

Benefits of Exercise Lesson: It involves discussing on how the participant will develop and maintain a healthy body.

Resting heart rate: This involves measuring the number of times the heart of the participant beats per minute at rest.

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Chapter Two

Review of Related Literature

The related literature research was reviewed under the following headings:

2.1 Conceptual Studies

- 2.1.1 Concept of Swimming
- 2.1.2 Historical Overview of General Swimming Assessment Methods
- 2.1.3 Physiological responses to exercise in swimmers using dry-land
- 2.1.4 Training the Youth Athlete
- 2.1.5 Youth Development Model
- 2.1.6 Historical overview of Exercise testing
- 2.1.7 Swimming Endurance and Speed

2.2 Theoretical Model/Framework

2.2.1 Theory of Training Adaptation

2.3 Review of Empirical Studies

2.3.1 The Physiological Demands of Swimming

2.3.2 The Biomechanical Demands of Swimming

2.3.3 Relationship Between Dry-Land Strength/Power Assessments and Swimming Performance

2.3.4 Effects of Strength Training On Swimming Performance

2.3.5 Challenges to Health and Well-Being for the Youth Athlete

2.4 Conceptual Model/Framework

2.5 Summary of Gap in Literature

Endnotes

2.1 Conceptual Studies

2.1.1. Introduction to Swimming

Swimming is a sport or activity in which participants use their limbs to move through water. Swimming is a sport that involves competition and is seen as a beneficial form of exercise for individuals of all ages and fitness levels. The sport may be done in a pool or in open water (e.g., in a sea or lake). Swimming is one of the most popular Olympic sports, featuring butterfly, backstroke, breaststroke, freestyle, and individual medley events¹. Four swimmers can compete in either a freestyle or medley relay in addition to these solo events. A medley relay is made up of four swimmers who each swim a different stroke, which are backstroke, breaststroke, butterfly, and freestyle in that sequence.

Swimming is one of the most well-liked sports, both competitively and recreationally, with a variety of distance events in breaststroke, front crawl, backstroke, butterfly stroke, free style, and individual medley. The body must be moved through water using the arm and legs in this individual and team activity. It involves a person moving by themselves through fresh or salt water typically for enjoyment, sport, exercise, or survival. Location is achieved through coordinated movement of the body, the limbs, or both. It must be acknowledged that excellent performance is crucial in competitive swimming².

Swimmers must cover the event distance in the shortest amount of time possible because the outcome of a race might ultimately be determined by fractions of a second in swimming competition. Success can be attributed to differences in body mechanics, physiology, and anthropometric factors, as well as a swimmer's ability to repeatedly overcome the resistance of the water and produce effective starts and turns. Swimmers are frequently referred to as overheated

athletes because they frequently sustain similar injuries. However, swimming is very different from other sports due to training in a prone position and the use of both arms and legs for propulsion, with 90% of the propelling force coming from the upper extremities³. Another key difference between swimming and land-based sports is that swimming does not include ground contact. Land-based sports use the ground as a point of reference for movement. Swimmers must therefore use their core as the pivot point of movement, reinforcing the requirement that they have a strong core in order to succeed in the sport.

Power training has the potential to increase muscular strength under dynamic circumstances. Power is the capacity to perform movements at a fast rate of speed or the capacity

to use a lot of strength in a short period of time. More than forty years ago, Hill first outlined the connection between the force, strength, and speed of muscle contraction (1938-2021). Swimming performance is a multi-factor phenomenon that takes into account energy, kinetic, hydrodynamic, anthropometric, and strength characteristics⁴. Strength and speed are key elements determining swimmer performance. Both scientists and coaches concur that training exercises should involve both land and water. Swimming strength and endurance training is done both on land and in the water. It has been demonstrated that combining endurance and strength training inhibits the growth of strength and power. One of the most crucial characteristics of a vehicle is mechanical strength, which has a significant impact on both the speed at which movements are carried out and the activities that call for both strength and skill.

Swimming is a weightless, cyclical sport in which individuals or teams of swimmers compete against one another over a range of lengths and swimming strokes. Cycling, rowing, jogging, kayaking, and other repetitive motion sports are examples of motor activities defined as cyclical⁵. One of the only sports where competitors regularly compete in a variety of events with varying distances and stroke techniques is swimming.

At the youth level, where swimmers routinely prepare to compete in a number of tournaments in order to increase their range of competing options, this is particularly obvious. As a swimmer who was trained from a young age to compete in a variety of events, Michael Phels is a good example. This gave him an advantage, and he went on to become the most successful Olympian of all time, winning 28 Olympic medals, including 23 gold, in the 100-, 200-, and 400-meter races using four different swimming strokes. Freestyle, backstroke, butterfly, and breaststroke are the four swimming strokes. Other medley events require a swimmer to compete

using all four strokes simultaneously. Sprint (50 and 100 meters), intermediate (200 and 400 meters), and long (800, 1,500, and 10,000 meters) distance classifications are frequently used to categorize the races ⁶. The three primary components of most swimming competitions are the start from the blocks, the turn off the wall, and the actual swim, with different technical standards for each stroke technique. Due to the wide diversity of swimming stroke techniques, event distances, and individual components, swimming is a complicated and challenging sport from a physical, technical, and tactical standpoint. Table 2.1 summarizes the gold medal winning times for each of the 34 swimming competitions at the 2016 Summer Olympics in Rio.

Table 2.1 Olympic gold medal winning percentages from Rio 2016 (Rio: Swimming 2016)

Event	Distance	Male	Female
Freestyle	50 m	21.40	24.07
	100 m	47.58	52.70
	200 m	1:44.65	1:53.73
	400 m	3:41.55	3:56.46
	800 m	----- 14:34.57	8:04.79

	1500 m	1:52:59.8	-----
	10,000 m		1:56:32.1
Backstroke	100 m	51.97	58.45
	200 m	1:53.62	2:05.99
Breaststroke	100 m	57.13	1:04.93
	200 m	2:07.46	2:20.30
Butterfly	100 m	50.39	55.48
	200 m	1:53.36	2:04.85
Individual Medley	200 m	1:54.66	2:06.58
	400 m	4:06.05	4:26.36
Freestyle Relay	4 × 100 m	3:09.92 ^a	3:30.65 ^d
	4 × 200 m	7:00.66 ^b	7:43.03 ^e
Medley Relay	4 × 100 m	3:27.95 ^c	3:53.13 ^f
^a Individual 100 m freestyle relay times of 46.97 – 48.10		^d Individual 100 m freestyle relay times of 51.97 – 53.41	
^b Individual 200 m freestyle relay times of 1:44.14 –		^e Individual times for the 200 m freestyle relay ranged from 1:53.74 to 1:56.69.	
		^f Individual times for the 100 m	

<p>1:46.03 100-meter medley relay timings ranged from 46.74 to 59.03.</p>	<p>medley relay ranged from 52.43 to 1:05.70.</p>
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However, it can be anticipated that these times would be significantly lower at your level.

2.1.2 Historical Overview of General Swimming Assessment Methods

1. Water-based methods

There has been a plethora of methods that have been used to assess swimmers. The earliest methods focused upon assessments carried out in the water. Such assessments were first initiated in the late 19th century, when swimming was established as a sport by inclusion in the first Olympic Games of 1896. The need for swimming assessments arose from increased competition in these Games and also in long distance swimming events, such as swimming the English Channel ⁷. The first reported water-based assessment method used towing of an active swimmer behind a boat and measured the forces generated during swimming using a dynamometer. ⁸ In later studies, active towing was used to measure water resistance during swimming. These studies employed the

use of different equipment, such as a resistograph ⁹, a modified resistograph ¹⁰. Another water-based assessment method included the measurement of speed fluctuations during swimming. This involved the use of a system of cables and pulleys ¹¹. The forces generated during swimming have also been assessed.

This method used a system of weights arranged vertically on a stationary platform ¹¹ or a platform moving at constant speed alongside the swimmer in a circular pool ¹¹. Furthermore, the deviation between extreme velocities during swimming has been assessed using a linear accelerometer ¹¹.

In the 1980s, a group of Dutch researchers developed the measuring active drag system (MAD-system ¹²). This technique involved the swimmer pushing pads that were fixed under the water to drive themselves ahead. A load cell monitored the pushing forces used by the swimmer. The active drag was then calculated using the premise that the mean propulsive force—that is, the force used to push the pad—exercised by the swimmer was equal to the mean drag experienced while swimming, under the presumption that the swimmer's swimming velocity during the measurement was constant. Due to its methodological limitations, the drag estimation utilizing the MAD-system can only be used for front crawl swimming without leg movements.

As a result, this method cannot be used to estimate the active drag that the swimmer experiences while swimming with their entire body. The fact that swimmers alter their velocity differently than actual swimming conditions is another issue with the MAD-system. The product of stroke frequency and length is used to compute swimming velocity. In contrast to reality, the MAD-system condition assumes that the swimmer's stroke length is constant and that the only factor affecting swimming velocity is the frequency of the strokes. On the other hand, another two

approaches can be used to measure the drag in different swimming strokes. However, they can only assess the drag during trials of maximum exertion.

These three systems have primarily been used to evaluate the drag experienced by swimmers, and the MAD-system is the only one that is able to evaluate active drag at various velocities among the three^{12 13}.

2. Dry-land methods

In addition to water-based assessment methods, there have been methods which have used determinations in the laboratory. Swimmers have been assessed in the laboratory using arm-cranking and cycling and also ergometry which attempts to replicate the front crawl swimming action (swim bench). The swim bench was developed in the late 1970s to be used in dry-land strength training of swimmers¹⁴. It comprises a dry-land exerciser that was specially designed to fulfil swimming specifications, such as accommodating resistance and to replicate the arm stroke characteristics of swimming. Later, the swim bench was also used in physiological assessment of swimmers¹⁵. This was due to its ability to circumvent the difficulties arising from waterbased testing. One of the difficulties associated with measurements of oxygen uptake during swimming is related to the use of gas collection apparatus. This involves the use of a mouthpiece with headgear, which may increase drag, thereby retarding swimming motion. In addition, the mouthpiece itself has been known to offer resistance to breathing¹⁶. More importantly, this arrangement poses a safety risk, as apart from the inconvenience it causes to the swimmer, there is possibility of water inhalation. Indeed, it was shown that it is possible to measure oxygen uptake of swimmers at increasing intensities of exercise using the swim bench¹⁷. Moreover, the opportunity to quantify exercise intensity as power output has provided opportunities for novel

assessment methods for swimmers. This has not been possible previously through use of any other type of swimming ergometry.

The most commonly used swimming assessment methods

A detailed description of the four most commonly used swimming assessment methods is given in the following section, with particular focus upon the respective ergometers. Swimming assessment methods can be classified into two main categories: a) water-based methods that use tethered swimming, measurement of active drag and flume swimming and b) dry-land methods that use swim bench exercise.

1. Tethered Swimming

Tethered swimming is the form of swimming exercise where the subject remains stationary whilst attached or 'tethered' to a cable and pulley system by means of a belt worn around the waist¹⁸. The amount of weight attached to the cable can be increased periodically, thereby forcing the swimmer to exert more effort to maintain his/her position, whereas the force exerted by the swimmer must be sufficient to maintain the pulley at a given height. Alterations in the original design of the stationary platform in tethered swimming led to the development of a moving platform. This system is called 'semi-tethered' swimming, as the swimmer is no longer stationary. In this system the pulleys are attached to the platform, which in turn connects with the subject. The platform can be positioned either in front of the swimmer moving at constant speed or behind the swimmer being pulled along the pool side by the swimmer. Further improvements in the use of tethered swimming led to the development of 'swimming power output system'¹⁹. When using this system the swimmer is tethered to a cable, which is connected to a computer. By use of specialised software, the forces that the swimmer generates while swimming can be converted to power

output. A diagrammatic representation of the 'swimming power system' is presented ²⁰. Tethered swimming is a useful method as it can be used to measure the forces generated during swimming and also to assess propulsive power.

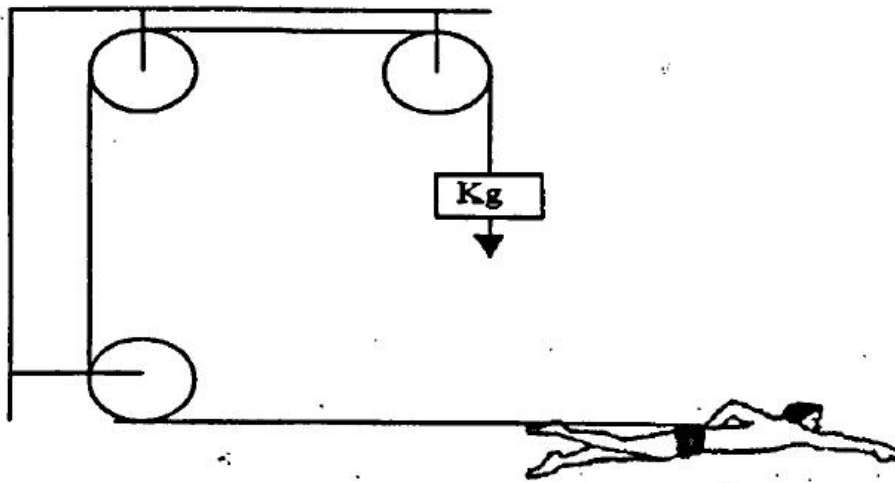


Figure 1: Tethered swimming showing the system of cables and pulleys and the way the swimmer is 'tethered' to the system. Redrawn from ²¹), Exercise Physiology: Energy, Nutrition and Human Performance, p. 191.

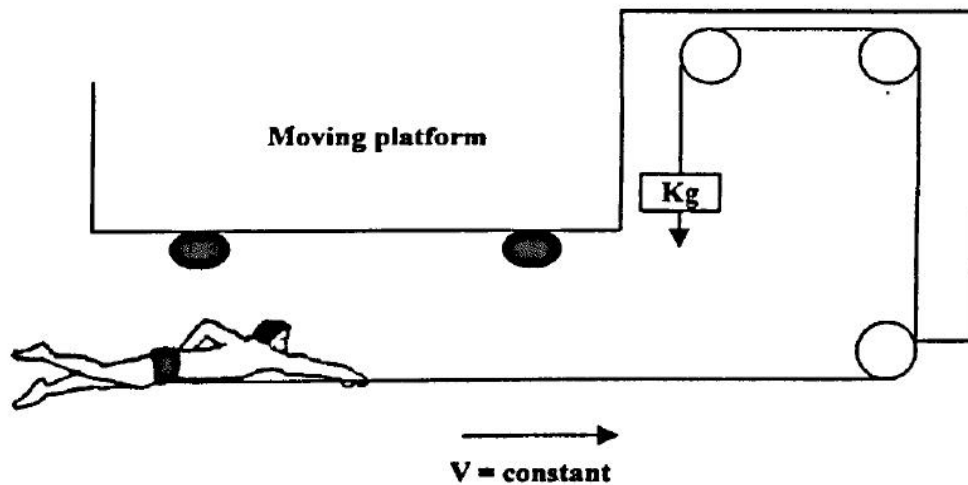


Figure 2: Semi-tethered swimming showing the platform moving at constant velocity alongside the swimmer and the different arrangement of the system of cables and pulleys. Redrawn from ²² Energetics of swimming in man, *Journal of Applied Physiology*, 237: 1.

Although tethered swimming is a useful tool in assessment of swimmers in the water, its use presents limitations that are mostly associated with the stationary position of the swimmer in the water. It has been suggested that during tethered swimming the movements of the arms and the legs through the water differ from free swimming. Also, swimming speed and drag are minimal ²³. It has also been postulated that the swimmers' technique during tethered swimming is not at all similar to that used in free swimming. Furthermore, tethered swimming measurements can only provide information on propulsive forces generated by the whole-body of the swimmer. In addition, it is difficult to use tethered swimming to assess the separate responses to arm or leg exercise at the same given swimming speed.

2. The MAD system

The MAD system has a similar structure to that of tethered swimming. This system was specially designed to measure active drag during front crawl swimming²⁴. It comprises a system of fixed push-off pads mounted 1.35 m apart on two 23-metre horizontal rods, which are placed 1.25 m parallel to each other.

This arrangement enables the swimmer to swim in both directions using the system. The rods are tied at each pool end and are fixed at 0.8 m below the water surface. At the end of the pool, one of the rods is connected to a force transducer linked to an on-line computer using a 12-bit analogue-to-digital converter that operates at a frequency of 100 Hz. This enabled the propelling force that the swimmer generates during the push-off action to be measured at each pad. Whilst swimming front crawl, the swimmer places alternate hands on the pads and performs the swimming action, thereby pushing on the pads and moving forward. It has been suggested that, at a constant velocity of swimming, the average propulsive force will be equal to the average drag force²⁵.

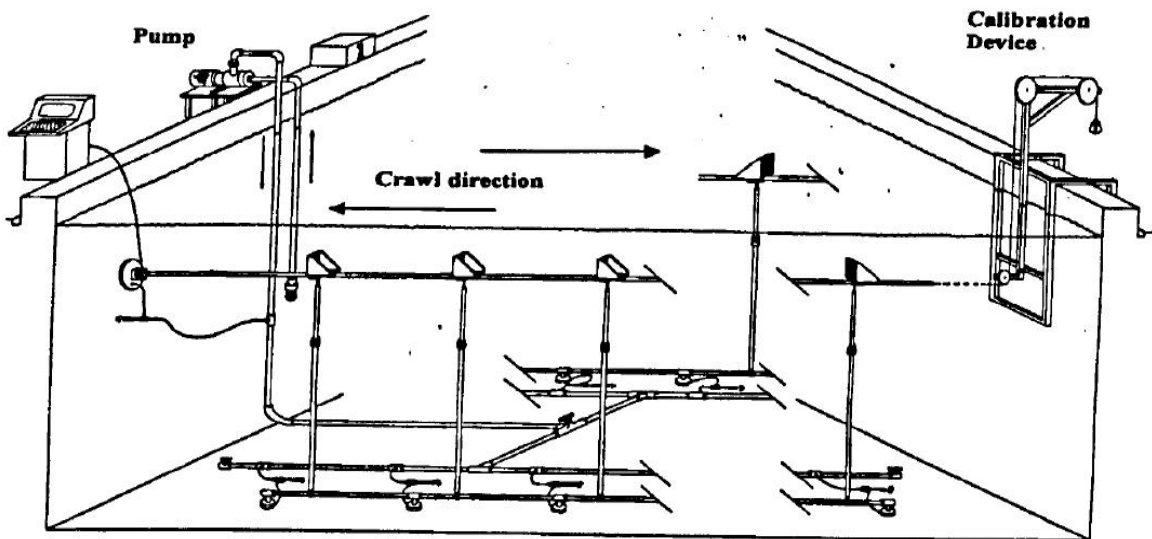


Figure 3. The MAD system showing the system of fixed push-off pads, the horizontal rods and the way these are fixed onto the pool end and under the water surface.

The MAD system is a useful innovation as it provides an alternative method for measuring propulsive power during front crawl swimming, but its use has certain disadvantages. One of these disadvantages is associated with possible alterations in swimming technique, which are made so that the arm-stroking pattern coincides with the fixed position of the push-off pads. Another disadvantage is that the current arrangement of the MAD system allows only measurement of active drag of the arm-pulling and not the legkicking front crawl action. The amount of active drag generated by leg-kicking has been indirectly estimated by measuring whole-body and arms-only active drag and subtracting the latter from the former ²⁶. These findings suggested that active drag during leg-kicking accounts for approximately 11% of whole-body propulsion. However, the active drag of the leg-kicking action during front crawl swimming was not measured directly and therefore, these findings must be viewed with caution. The contribution that the leg-kicking component of front crawl swimming makes to the overall physiology of Swimming must be further investigated before definitive conclusions can be made.

3. The Swimming Flume

The swimming flume allows swimmers to simulate closely their 'pool' swimming strokes. Otherwise termed the swimming treadmill (Figure 4; ²⁷), it consists of a tank where water can be circulated at varying set flow rates. Sometimes, it is surrounded by an environmental chamber, which controls atmospheric pressure and other environmental conditions during swimming. It operates by propeller pumps that circulate water past the swimmer, who attempts to maintain

body position in the flume. The pump circulation can be increased or decreased to vary the speed at

which the swimmer must swim. The swimming treadmill has been used to assess physiological measures and biomedical aspects during swimming as it is possible to simulate actual performance conditions when using this equipment ²⁸.

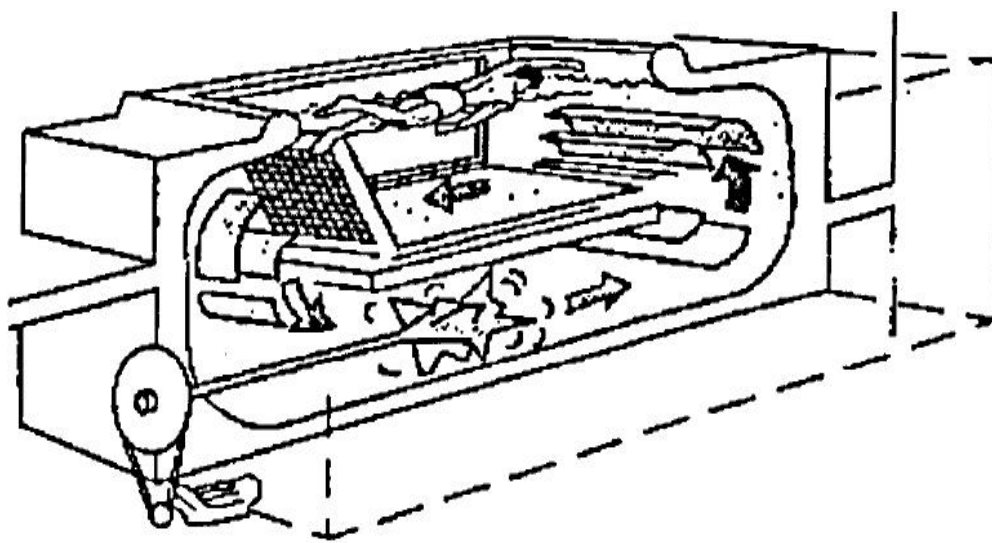


Figure 4: The swimming flume showing the tank, the propeller pump and the anticlockwise flow of water.

The swimming flume is considered to be the most successful technical innovation in the swimming world, as it provides the ideal environment for physiological measurements of swimmers during swimming ²⁹.

However, this sophisticated assessment system can only assess physiological measures in relation to swimming speed. It is not possible to measure propulsive power, or indeed, any kind

of power output measure from the exercising limbs of the swimmer. The swimming flume is an elaborate method of testing physiological characteristics of swimmers during swimming. The main advantage of this method is that the test environment is identical to the swimmer's training environment. Another advantage is that it allows standardisation of procedures, especially of those referring to swimming speed, which results in increased accuracy and reproducibility of measurements. Swimming speed can be easily manipulated either to remain constant throughout a set distance or to increase gradually. This allows determination of physiological measures such as maximum oxygen uptake ³⁰.

The main disadvantage of using the swimming flume is the high cost of installation and maintenance of this equipment. Contrary to its equivalent for runners (treadmill), the swimming flume requires spacious facilities for its installation and specialised personnel for its operation and maintenance. In most cases, research institutions are unable to utilise the required space or finances to maintain such expensive equipment within their facilities. Other disadvantages include the quantity of energy lost in turbulence and the fact, that the amount of work performed is measured only in the direction of progression ³¹. Also, in water-based assessments using the swimming flume, it is not possible to elucidate the contribution that leg-kicking makes to the overall physiological responses to swimming whilst the arms and the legs are exercised simultaneously.

4. The Swim Bench

The swim bench is a dry-land ergometer which was initially developed as a training device to be used in strength training of swimmers, but later was also used in physiological assessment of swimmers ^{32, 33}. In the late 1970s, the swim bench incorporated the structure of an early

swimming machine which was designed back in 1857 by Lambert Cowell to be used in teaching of swimming strokes ³⁴. It consists of a bench for the swimmer to lie on and a pulley system which offers semi-accommodating resistance. It is also equipped with a speed-controlling mechanism that accelerates to a set constant velocity. This acceleration is possible throughout the full range of motion. The

swimmer pulls on pulley-ropes and the resistance elicited from the apparatus is designed to match the resistance experienced during actual swimming at any given point in the range of motion of the muscle group's being exercised. This resistance is provided by a shunted generator' and is electromagnetic, not frictional. A built-in electronic read-out unit records the force produced and the distance by which the pulley-rope is extended, thus enabling the mechanical work performed to be measured ³⁵. The analogue output on the 'biokinetic' (Biokinetics is a trade mark of Isokinetics, Inc.) swim bench drives a high-speed chart recorder to produce permanent record of stroke and force characteristics. A diagram of the 'biokinetic' Swim bench is shown in Figure 5.

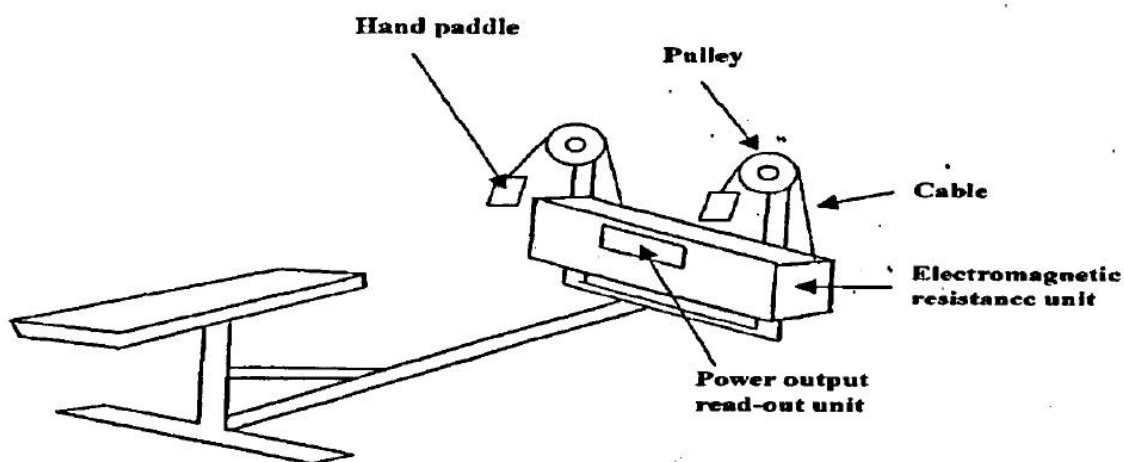


Figure 5: The 'biokinetic' swim bench showing the pulley system, the hand paddles, the analogue power output recorder and the connection to the electronic unit.)

Recent developments in swim bench structure (H. and M. Engineering, Gwent, Wales, UK) have added a transducer unit with an interfaced microprocessor. This new swim bench design has allowed physiological measures, such as oxygen uptake (V_{O_2}) to be related to given power outputs ³⁶. Resistance to the application of tension is such that the pull-rope pays out a velocity, which ranges up to a pre-set maximum. This has termed maximal pull velocity. The resistance unit offers

seven settings (range: 0-6) of maximum pull velocity on a continuous scale. Being computer-interfaced, this 'advanced' swim bench offers the opportunity to assess power output at different exercise intensities ³⁷. This has been made possible using a specially designed computer Programme (HK. Smith, University of Sunderland). This program receives the numerical data from the interface unit and converts it into a power output reading displayed on screen of an IBM compatible computer, whilst the swimmer is exercising. They are secured to the bench by a suitably mounted strap around the torso to restrain movement of the lower body when exercising the arms. The way the subject is exercising on the interfaced swim bench is shown in Figure 2.6.

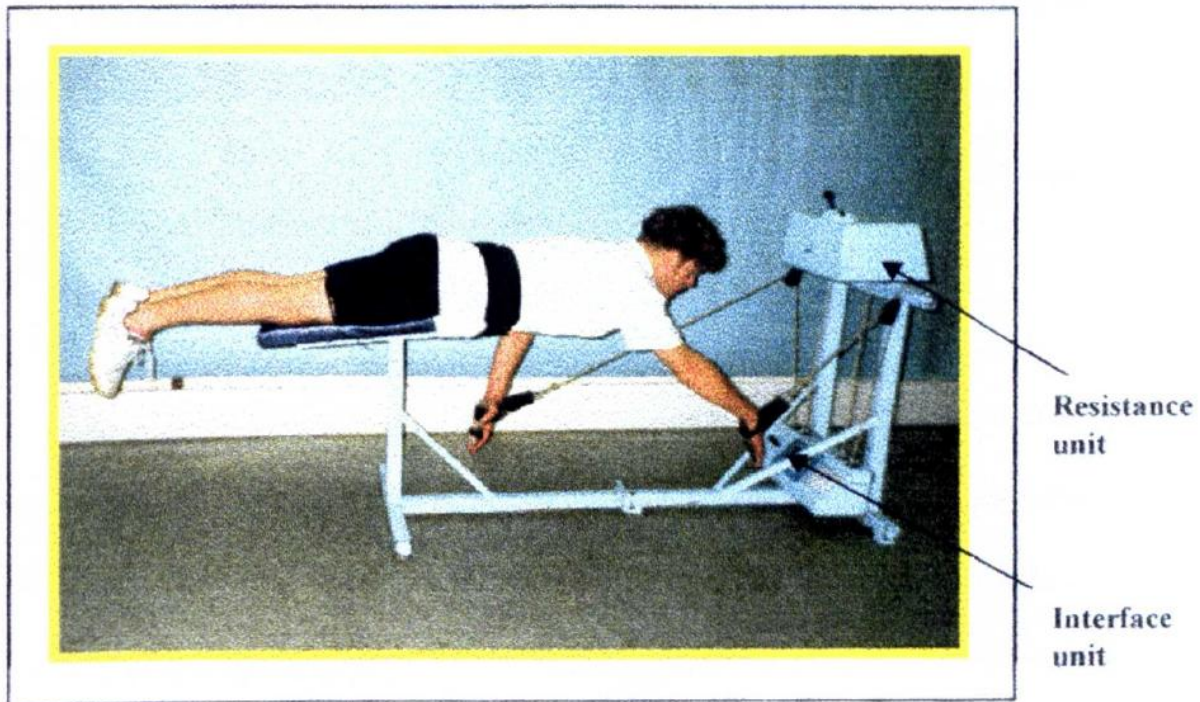


Figure 6: The 'advanced' swim bench showing the resistance and interface units

There have been many reasons for which the use of the swim bench in strength training of swimmers has been advocated. Research findings have indicated that high-speed strength training

on the swim bench significantly increases the strength of swimmers and improves swimming performance. It has been documented that, although it cannot duplicate the arm and hand actions executed in the water, nevertheless the swim bench allows the swimmer to incorporate (in one motion most of the muscle groups and the mechanics required during swimming. Also, the resistance the swim bench offers provides an effective training overload that can increase muscle strength specific to swimming ³⁸. Such research set the basis for a series of measurements to

monitor improvements in performance when using the swim bench as a training aid (for the improvement of strength).

Similarly, there have also been reasons for which the use of the swim bench in swimming research has been favoured. First, the measurement of power output is one of the main advantages of the swim bench³⁹. This is potentially useful in physiological assessment of swimmers for the same reasons as have been previously demonstrated in assessments involving the use of cycle ergometry for cyclists⁴⁰. There have been studies that have assessed upper and lower limb external power output using arm-cranking and cycling ergometry, thereby enhancing the understanding of the role of power in swimming, but these types of ergometers have been shown to have poor specificity with swimming. Some water-based investigations have assessed propulsive power and for, but these findings can not be compared to power output of the exercising limbs. In addition, the design of swim benches with electromagnetic resistance has facilitated the measurement of muscular power in a pulling action similar to that of free swimming. Such measurements cannot be performed using water-based swimming ergometry.

Another obvious criticism has been that the swim bench is used solely to assess the responses to arm-pulling exercise. It has not been possible to assess the responses to leg-kicking using this equipment. In many instances the use of the swim bench, and indeed, the assessment of upper body responses to exercise in swimmers, has been justified on the basis of the perceived contribution of the arms and legs to the overall physiological responses to swimming. It has been previously suggested that leg action contributes very little to overall propulsion in front crawl (approximately 11%; However, there is a need to assess the physiological responses to leg-kicking using direct measurements. Indeed, recently efforts have been made to address this problem, although new developments are only in their early stages⁴¹.

2.1.3 Physiological responses to exercise in swimmers using dry-land

Apart from the aforementioned water-based methods; there have also been dry-land methods in assessment of physiological characteristics of swimmers. One of these methods has involved the use of the swim bench. Studies that have employed swim bench testing have included determinations of cardiopulmonary responses to exercise adaptations to training using surgical tubing⁴² anaerobic power and also ergometric analysis of age group swimmers. Furthermore, swim bench measurements have been compared with measurements of swimming performance. These studies have related physiological variables to middle distance swimming performance, and arm power to sprint swimming performance. Also, oxygen uptake and bioenergetic characteristics from swim bench and waterbased testing have been compared. Swim bench measurements have also been compared with tethered and flume swimming measurements. These studies have investigated the relationship between tethered and swim bench V_{O2max} ⁴³. Other studies have compared critical speed as measured using flume swimming with critical power as measured during swim bench exercise.

The usefulness of swim bench measurements has also been evaluated in relation to training. These studies have determined the effects of swim bench training, intense swimming training, arm training and training using hand-paddle. Swimbench measurements have allowed quantification of arm power output in relation to exercise intensity⁴⁴. However, the design of the

swim bench has not allowed measurement of leg-kicking power output and thus, swim bench findings can only have implications for the training of the arms in swimming.

Establishing Training Zones

One of the most important training components in the sport of swimming is the overall training volume within a program that can be divided into various training intensities or zones. The creation of training zones assists in the successful planning of training programs by assuring regular exposure to a variety of training stressors and monitoring for negative effects, such as overtraining. The majority of national and international governing organizations have developed some sort of training zone model for coaches based on suggested heart rate ranges in relation to the maximum and range of typical blood lactate concentrations. A design of a five-zone paradigm that is often used in an Irish swimming context is detailed below in Table 2.2.

Table 2.2: A popular five-zone training scheme used in Irish swimming (Sweetenham and Atkinson, 2003)

Training Zone	Description	HR (bpm)	BLa (mM)	RPE
Zone 1	Aerobic Low Intensity (i.e. Base conditioning and technical training)	>50	< 2	< 9
	Aerobic Maintenance/Development (i.e. Base aerobic training)	40 – 50	2 – 4	10 – 12
Zone 2	Anaerobic Threshold (i.e. Training at	20 – 30	3 – 6	14 –

	maximal lactate steady state)			15
Zone 3	Aerobic Overload (i.e. High-intensity training at VO_{2max} . Includes heart rate and critical velocity training)	5 – 20	6 – 12	17 – 19
Zone 4	Lactate Production (i.e. Race pace training)	5 – 15	8 – 15	17 – 19
	Lactate Production/Tolerance (i.e. High-intensity exercise with moderate rest)	0 – 10	12 – 20	19 – 20
Zone 5	Sprinting – ATP-PC (i.e. High intensity training of n/a short duration with long rest intervals)		n/a	n/a

Abbreviations: HR (bpm), heart rate measured in beats below maximal; BL_a, blood lactate concentration; RPE, rating of perceived exertion (6 – 20 scale)

However, general training zone recommendations like Table 2.2 do not account for individual differences in the relationship between heart rate and blood lactate responses or activity-specific variations in the body's reaction to exercise. Many of the lines dividing each training zone are also not well defined in the underlying physical events ⁴⁵. For instance, in Table 2.3, the distinction between zones 3 and 4 is purely based on heart rate and blood lactate levels. Utilizing the first and second ventilatory turn points, new research has created a three-zone model (see Figure 7). The aerobic (LT1) and anaerobic (LT2) thresholds were previously shown to correspond to the first (VT1) and second venous turn points (VT2), which were established in investigations utilizing breath-by-breath gas exchange measurements. As seen in Figure 7, a three-zone model has an advantage over a five-zone model in that the ventilation measurements give rise to two distinct physiological events that are easy to distinguish in a lab setting. Zones for low-intensity training (Zone 1), moderate-intensity training (Zone 2), and high-intensity training (Zone 3) can be

separated out of the three zones model.

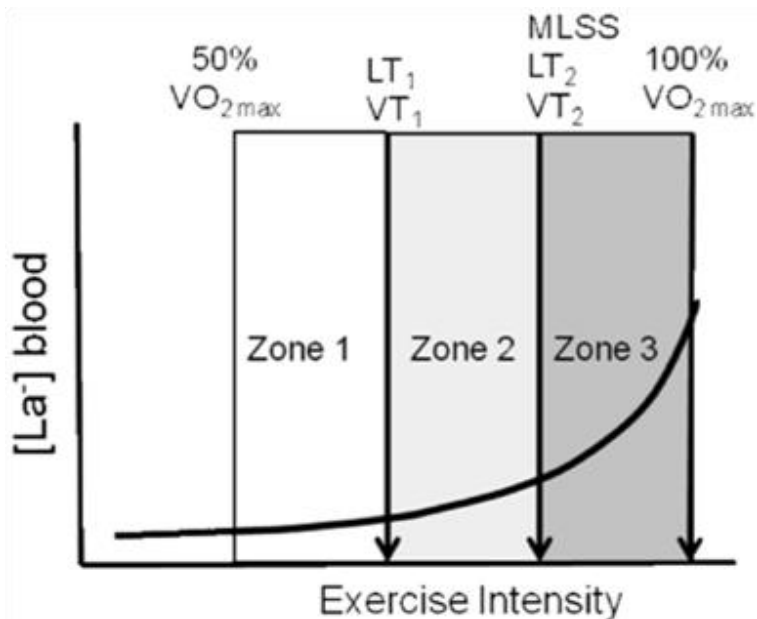


Figure 7: – A three-zone training design proposed by ⁴⁶. Abbreviations: Blood lactate concentration, La-; maximum oxygen uptake, V O₂max; ventricular threshold, LT; maximum lactate steady state.

Quantifying and Prescribing Training Zones

It takes a mix of techniques to accurately qualify and prescribe each training zone, including blood lactate concentration, percentage of maximum heart rate or VO₂max, and rating of perceived exertion (RPE). Due to the drawbacks of depending solely on one measure, this is the case (such as individual variations in heart rate or blood lactate concentration). Continuous training that is performed below VT₁ and LT₁ or at stable blood lactate concentrations of less than 2 mM is referred to as low-intensity training, or LIT, sometimes known as "zone 1 training." During LIT, the average heart rate is 80% of the maximum heart rate. Perceived exertion ratings for LIT sessions have been recommended to be between 4 and 13 on the Borg scale of 1 to 10, and between

6 and 20 on the Borg scale. A low-intensity, high-volume (HVT) training program is one in which low-intensity training is regularly carried out in high volumes⁴⁷. MIT, also referred to as "zone 2" training, is defined as exercise performed between VT1 and VT2, LT1 and LT2, or at blood lactate concentrations of 2 to 4 mM. While RPE values of 5 to 6 have been recommended for the Berg 1 to 10 scale and 14 to 16 for the Berg 6 to 20 scale, heart rates for MIT participants normally range between 80 and 87% of HRmax. Modulated-intensity training, which is usually done in a continuous or intermittent training manner, is frequently known as a threshold training program⁴⁸.

Exercise that results in blood lactate concentrations above 4 mM or above VT2 and LT2 is referred to as high-intensity training (HIT), also known as "zone 3" training. This is frequently done in the form of numerous short bursts of activity (less than 45 seconds) to long bursts of exercise (between two and four minutes), interspersed by active or passive rest intervals. The recovery times are frequently determined by fixed work-to-recovery ratios (such as 1:1, 1:2, or 2:1) or by a fixed threshold for the heart rate's return to maximum. Heart rate values that are typically used to describe the HIT range are > 87% of HRmax (Seler 2010). While projected RPE values of around 7 for the Borg 1–10 scale and approximately 17 for the Borg 9–20 scale. High-intensity training is usually carried out in fewer volumes than other training zones due to the related physiological effort, and is frequently referred to as a low-volume high-intensity training program⁴⁹.

Applications and Adaptations of each Training Zone

Low-Intensity Training

It is well known that elite and well-trained athletes complete substantial quantities of LIT during the training season's preparation and performance stages. Between 70 and 94% of their training is completed as LIT in circular activities like rowing, cycling, cross-country skiing,⁵⁰ and running. It has been found that advanced swimmers perform 80% of their training as LIT,⁵¹ which is consistent with the advice given to swim coaches for both junior and senior swimmers in all competitions. Alexander Popov, the double Olympic winner in the 50 and 100-meter freestyle, was really said to have exercised for at least an hour every day for the whole season while participating in sprint events that lasted only 50 seconds. LIT causes a variety of training adaptations that are diverse in nature and clearly affect the body's physiological and neuromuscular systems. Among the physiologic adaptations brought on by LIT are increases in blood and plasma volume, cardiac output, muscle and cerebral blood flow, changes in muscle capillary density, and mitochondrial volume. These physiological changes result in increased oxygen delivery to the muscle during exercise as well as increased oxygen consumption by the muscle. These physiological adaptations may not occur to the same extent in well-trained athletes, despite the fact that many of these adaptations have only been seen in recreationally active and untrained individuals⁵². Despite this, several LIT-induced performance changes, including as elevated VO₂max, enhanced exercise economy, elevated velocities at LT1 and LT2, and more, are routinely seen in well-trained athletes. These changes in performance are caused by increased muscular activity and oxygen delivery, which both increase efficiency and physical work capacity, both of which should directly affect performance⁵³.

Incorporating LIT into the training regimens of sports like swimming has a variety of practical applications in addition to the physiological and performance adaptations to LIT. LIT has been demonstrated to speed up recovery from HIT, increase glucose absorption, enhance body composition, and get the muscles and bones ready for more strenuous exercise, according to a review article by ⁵⁴. The proposed mechanisms behind LIT improving recovery are that the increases to muscle capillarization provided by LIT may help to improve the delivery of oxygen to working muscles and thus increase the removal of metabolic by-products. This is an important consideration to make if recovery before and after HIT sessions or competitions is to be given priority, especially in sports like swimming where athletes typically compete in a variety of events over the course of multiple days. In order to encourage this, swimming coaches have previously emphasized the significance of LIT in the healing process. Improving body composition is an important component that has previously been mentioned ⁵⁵. Swimmers' ability to drag through the water is improved by maintaining a clean body profile (see 2.3 The biological demands of swimming). LIT may also be used to enhance and develop the neuromuscular network in the brain. ⁵⁶. Swimming is a cycle motion, which means the muscles contract repeatedly. As a result, by practicing the movement pattern, technical competence is achieved. This may be of utmost significance for swimming because of the intricate relationship between physics and biomechanics, which means that a swimmer's technical skill in reducing resistance or drag and boosting propulsion is directly tied to physiological requirements. A higher volume of repetitive practice may be necessary for developing efficient swimming methods compared to in-season sports like running. Similar to rowing and cycling, swimming is a non-weight-bearing sport, hence the demands on the muscular-skeletal system are relatively low.

Because of this, swimmers can run longer distances without suffering from the same level of ectopic muscle injury as activities involving weight bearing.

Moderate-Intensity Training

It has been demonstrated that senior swimmers complete 10% of their training as MIT, but this percentage distribution of MIT may change depending on the swimmers' age group competition or competitive event.⁵⁷ Due to the prevalence of LIT in swimming programs, certain MIT is frequently done incorrectly, especially at the juvenile level because the physical demands of each swimming stroke may vary based on the swimmer's biomechanical or technical efficiency. The best training zone or intensity to improve physiological and performance in endurance events has previously been suggested as moderate-intensity training. However, as LIT and HIT gain prominence among academics and coaching circles, MIT's appeal to swimmers may be waning. Even if MIT is not the main focus of the course, its performance and physical adjustments resemble those of LIT⁵⁸. MIT is carried out more vigorously than LIT (2 mM blood lactate), which can lead to increased physiological stress levels. It's crucial to consider the risk of increasing the athlete's physiological stress levels while using MIT with training programs. People⁵⁹ looked at the impact of LIT and MIT sessions on the precise healing of the autonomic nerve system (ANS) in well-trained runners. The MIT sessions included one hour of MIT performed between VT1 and VT2, and the LIT sessions included either one or two hours of LIT performed below VT1. The recovery of the ANS was evaluated using heart rate variability, and it was found that both LIT sessions resulted in less autonomic stress than the MIT session. This might be a factor in the fact that exceptional and skilled athletes carry out a substantial percentage of their LIT.

High-Intensity Training

HIT is a tool that coaches have used for a very long time to improve athletes' performance. Although the precise origins of the term are debatable, many believe that the German athlete Waldemer Grähler, who was active in the 1930s, is responsible for coining the term "interval training"⁶⁰. Grähler thought that alternate intervals of intense exercise and recovery were an efficient stimulant for the development of the heart. He was supposed to have been significantly influenced by Dr. Hans Reindell, a physiologist. Interval training was reportedly adopted by a number of highly successful runners in the late 1940s and 1950s. Emil Zatopek, who won gold medals in the 5,000 m, 10,000 m, and marathon races in the 1952 Olympics, is the most well-known runner to have achieved success during this time. A group of Swedish physiologists led by Per-Olf Strand released the first study on intermittent exercise, which showed how controlling activity duration and rest intervals might have a major impact on the physiological reactions to intermittent exercise. This volunteer work laid the groundwork for all subsequent HIT research as well as interval training. The particular amounts of HIT performed by well-trained athletes in cycling competitions varied greatly from 1 to 57%, depending on the training paradigm used. The quantity of HIT that swimming coaches advise depends on the stage of the season, the unique requirements of the swimmer for a particular race or practice, and the coaches' chosen training approach. Sweetenham and ⁶² suggest that 5 to 30% of training should involve race pace/hit. However, there are instances of highly accomplished swimmers from other countries who almost exclusively employ HIT. In order to train at a volume of 9 to 11 kilometers per week, Michael Andrews, the 2016 World Champion in the 100-

meter medley event, reportedly used a USRPT program that is similar to HIT. This is in contrast to other competitive swimmers' training logs, including those of Alexander Popov, the twice Olympic champion in the 50 and 100 m freestyle,

who was claimed to train between 40 and 100 kilometers per week depending on the time of the season and primarily using LIT. A total of reviews looking into HIT have been completed in the past 20 years^{63,64}. Although they frequently occur sooner and to a greater extent, especially in athletes who have never engaged in HIT before, the psychological and performance modifications brought on by HIT are comparable to those brought on by LIT and MIT. According to a review by ⁶⁵, increased skeletal muscle oxidative capacity, higher levels of glycogen at rest, lower rates of glycogen use and lactate production during matched-work exercise, increased capacity for whole body and skeletal muscle lipolysis, and improved peripheral vasculature structure and function are just a few of the physiological changes brought on by HIT. A shortcoming of the available literature in this area is that the majority of these psychological adaptations to HIT were found in investigations on recreationally active or employed individuals. Well-trained junior and senior athletes in cyclical sports like running, swimming, cycling,⁶⁶ and ⁶⁷cross-country running have been the subjects of several HIT studies. In well-trained athletes, HIT interventions have been found to increase skeletal muscle buffering capacity, skeletal muscle lipod oxidation, and the ability to engage a larger volume of muscle mass (i.e., recruitment of fast-twitch motor units). In contrast to previous findings, however, no adaptations to skeletal muscle oxidative capacity have been found. Despite this, a variety of performance changes to the HIT have repeatedly been found to take place, such as improved $\dot{V}O_{2max}$ ⁶⁸ velocity at $\dot{V}O_{2max}$ ⁶⁹ and velocity at LT1 or LT2 ⁷⁰. As a result, it has been repeatedly found that HIT therapies improve performance in events lasting between 30 and 40

minutes. In a non-weight-bearing sport like swimming, the multiple physiological and performance changes that HIT has experienced may theoretically have even greater applicability. Compared to a weight-bearing sport like running, swimming puts less environmental stress on the musculoskeletal system, allowing swimmers to possibly do more HIT

and promote more physiological and performance adaptations. Another potential use for HIT is in the biomechanics of swimming in venues with fast race speed. Studies using two- and three-dimensional mathematical analysis show that SI remains steady when swimming intensity increases, while SR increases and SL decreases⁷¹. The most significant biomechanical changes to swimming technique occurred at swimming intensities above the LT2, suggesting that HIT may be a valuable approach to improve swimming biomechanics (i.e., zone 3 or HIT).

2.1.4 Training the Youth Athlete

The Youth Athlete's Physical and Physiological Development

One must first understand the physical and physiological changes that young athletes go through as they age in order to fully understand the training techniques utilized by young swimmers. The definition of "maturation" is the rate and duration of development toward a fully developed psychological state. There are several various stages of maturation, including the prenatal, childhood, adolescent, and adult stages⁷². For the purposes of this the, the interests of children and adolescents are of prime importance. The childhood phase lasts from birth to age 12, whereas the teenage phase is from age 12 to age 18. Puberty, which produces a number of physical changes in the body, including increasing height and body mass, the emergence of secondary sex traits, and the ability to reproduce, takes place during the adolescent phase. However, individuals of the same chronological age as themselves can develop at different rates

and times. Therefore, when conducting research on young athletes, it is crucial to determine their maturity status. The childhood phase spans the years from 2 to 12 whereas the teenage period covers the years from 12 to 18 years of age. Puberty, which produces a number of physical changes in the body, including increasing height and body mass, the emergence of secondary sex traits, and the ability to

reproduce, takes place during the adolescent phase. However, individuals of the same chronological age as themselves can develop at different rates and times. Therefore, when conducting research on young athletes, it is crucial to determine their maturity status. Common methods of determining adult age include skeletal age and secondary sex characteristics ⁷⁴. However, older evidence of secondary sex features, like public hair, can be intrusive, and the bulk of applied sports science practitioners rarely have access to older evidence such as handwriting radiography. Using a predictive equation, a simple and effective technique for predicting years from peak height velocity (PHV) has been created by ⁷⁵. The term "PHV" refers to the stage of development when, as shown by straightforward anthropometric measurements, the rate of height growth is at its greatest. Equation has been widely used in pediatric research, but it has certain drawbacks, including accuracy increases as participants get closer to their PHV and accuracy declines as they go away from it. Depending on their age and stage of development, young athletes may react physiologically differently to a short burst of exercise. According to ⁷⁷, the anaerobic energy system is less well developed in pre-eminent athletes for a variety of reasons. Children's lower limb muscles before puberty have a much higher percentage of slow-twitch (Type-I) fibers than those of adults; post-pubescent athletes did not show this difference. Additionally, the lower anaerobic capacity in pre-pubescent athletes compared to post-pubescent athletes and adults may also be explained by the decreased activity of anaerobic enzymes and the

limited generation of muscle lactate in comparison to adults, ⁷⁸ suggests that fat oxidation has a greater impact on young athletes' energy metabolism than it does on adults. Prior to puberty, prolonged exercise frequently exposes lower reproductive exchange ratio values. Additionally, increased levels of glycerol release, growth hormone, and free fatty acid mobilization lend credence to the notion that adolescent athletes are more dependent on fat oxidation than adults are. The findings of Study ⁷⁹

are consistent with more current research that indicates pre-pubescent athletes rely more on aerobic metabolism and have less fully developed anaerobic energy systems than adults.

These issues have led some authors to argue that pre-pubescent athletes should minimize their use of anaerobic activity and instead prioritize aerobic exercise⁸⁰. But more recent data on how pre-eminent athletes respond to anaerobic training (like HIT) challenges this exercise ⁸¹. For instance, ⁸² researchers looked into the effect of HIT on swimmer performance in pre-pubescent swimmers and found that both sprint (50 and 100 m) and long distance (2,000 m) swimming events, including $\dot{V}O_{2peak}$ and BL_{peak} , saw a noticeable improvement in performance. The findings of the review by ⁸³, who contend that modern athletes only generate a limited amount of muscular lactate, are at contrast with the 20.1% increase in BL_{peak} . HIT appears to be a successful training regimen for ambitious athletes as a result. Similar to adolescents, post-pubescent athletes have also been discovered to benefit from HIT interventions. It is commonly known that children frequently engage in unstructured play that may be categorized as a repeated sprint activity, or HIT (such as competitive games on the playground), and perhaps high intensity activities would be a more natural training strategy for children. Additionally, it has been demonstrated that younger athletes have better recuperation skills and a higher resistance to

fatigue when engaging in high-intensity exercise. This may be due to their greater aerobic metabolism, different motor unit recovery, improved cardiorespiratory recovery abilities, and/or reduced generation and/or more efficient removal of metabolic byproducts (such as blood lactate) compared to adults⁸⁴. Because of this, HIT therapies may be particularly suitable for young athletes, especially those in the pre-pubescent stage, and customized to their physiology.

2.1.5. Youth Development Models

Numerous guidelines detailing long-term models of youth development that aim to increase both physical activity levels and sporting success in young people have been published as a result of the evidence-based shift toward holistic development that focuses on improving the health and well-being of youth participating in sport⁸⁵. Itván Baly, a Canadian sports scientist, first suggested the Long-Term Athlete Development (LTAD) concept in the late 1990s. Since then, several athletic associations throughout the world have embraced it. The LTAD model aligns the prescription for training with the time of maturity rather than chronological age in an effort to better individualize training regimens for you. According to the LTAD model, training advice should be personalized based on a person's developmental stage in order to take advantage of "windows of opportunity" for the growth of particular athletic components including motor skills, speed, aerobic capacity, and strength⁸⁶. There are times during development known as "windows of opportunity" when training-induced adaptations for each athlete component may be expedited⁸⁷. The LTAD model has distinct ages: 1) ACTIVE START (males and females 0 to 6 years); 2) FUNDAMENTALS (males and females 6 to 9 years; and 6 to 8 years); 3) Learning to Train (9-12 years for men, 8-11 years for women); 4) Training to Train (12-16 years for men, 11-15 years

for women); 5) Training to Compete (16-18 years for men, 15-17 years for women); 6) Training to Win (18+ years for men, 17+ years for women); 7) Active for Life (Enter at Any Age).⁸⁸ The chronological age ranges and developmental stages may slightly vary because this model has been altered numerous times to accommodate the particular needs of various sports. A modified LTAD model has come under a lot of scrutiny in swimming. ⁸⁹ examined how the "Swimmer Pathway" paradigm, which was first established in 2003 by the Amateur Swimming Association (ASA) in the UK, should be interpreted and used. The Swimmer Pathway's excessive emphasis on training

volume had led to a neglect of technology, according to the swimming coaches Lang and Light (2010) interviewed, who included six elite and five non-elite English swimming coaches. Table 2.3 lists the suggested training volumes for the Swimmer Pathway.

Table 2.3 the training recommendations of a swimming-specific LTAD model – The Swimmer Pathway (Lang and Light 2010)

	Fundamental	SwimSkills	Training to Train	Training to Compete	Training to Win
Chronological/ biological age	Male: 6 – 9 Female: 5 – 8	Male: 9 – 12 Female: 8 – 11	Male: 12 – 15 Female: 11 –	Male: 15 – 18 Female: 14 –	Male: 18+ Female: 16+

			14	16	
Recommended number of sessions per week	5 – 6 general sports	4 – 6 swim-specific, plus additional participation in other sports	6 – 12 swim-specific, including land work ^a	8 – 12 swim-specific, including land work ^a	10 – 15 swim-specific, including land work ^a
Recommended number of hours per week	2.5 – 4.5 hours general sports	4 – 7 hours swimming, plus 1 – 2 hours land work ^a	12 – 24 hours swimming, plus 2 – 3 hours land work ^a	16 – 24 hours swimming, plus 3 – 4 hours land work ^a	20 – 24 hours swimming, 3 – 6 hours land work ^a
Recommended training volume per week	None stated	8,000 – 16,000 m	24,000 – 32,000 m	24,000 – 52,000+ m	> 44,000 m, depending on specialism ^b (s)

^aLand work, strength and conditioning training; ^bSpecialism, specialist swimming stroke (s).

According to ⁸⁹, there is a "window of opportunity" for aerobic development during the one-year period of maturation (males 12–15 years and females 11–14 years), so the objective should be to "build the engine" using HVT. This is why the emphasis on training volume, especially during the Training to Train stage (12–24 hours of swimming per week), is in line with their recommendations. An expert commentary on the Lang and Light (2010) study by ⁹⁰ suggests that preventing the development of the aerobic energy system during maturation is crucial for everyone who swims competitively in the future because the aerobic system is linked to the swimmer's efficient recovery during HIT and competition. In order to maximize training adaptations during the "window of opportunity" for aerodynamic growth, HVT is crucial during the Training to Train

stage. Furthermore, advises HVT to be used during the "Training to Train" stage to maximize the development of the thorax and diaphragm, which are expanding at their quickest rates at this time. The authors draw the conclusion that an athlete's likelihood of succeeding as a senior swimmer will be diminished by excessive anaerobic training during the Training to Train stage. A review article by ⁹¹ looked at the literature to determine whether it offered any evidence in support of the LTAD model's notion of "windows of opportunity."⁹¹ found that the data supporting the "windows of opportunity" is largely anecdotal and the consensus lacks empirical evidence, so adopting training prescriptions based on these "windows" should be approached cautiously. There are risks associated with early specialization and intense training, particularly if the "windows of opportunity" are taken too literally, as seems to have happened with the

modified LTAD model for swimming in the Lang and Light (2010) study. Despite this, the LTAD model has improved coaches' and practitioners' understanding of the significance of physical principles and biological maturation throughout training. The Youth Physical Development (YPD) model has gained popularity recently and is recommended to offer a more empirically supported approach to youth development⁹¹. The YPD model gives an overview of athletic development from early childhood (2 years of age) to adulthood (21+ years of age), while identifying when and why each athletic component's training (such as strength, power, speed, agility, endurance, etc.) should be prioritized. The YPD model's philosophy permits individualization, places the athlete as the center of attention, and prioritizes the development of the child over performance outcomes. The LTAD model is still commonly used in Ireland, hence for the purposes of this study, the training recommendations for each developmental stage for Irish swimmers would be of interest.

Molecular Pathways of HIT and HVT

Although there is still much to learn about the molecular processes for skeletal muscle to adapt to different training conditions, a number of recent reviews have shed some light on this intricate process. It is hypothesized that HIT techniques, which frequently involve high-intensity contractions, reduce intramuscular ATP (adenosine triphosphate) concentrations, preventing a steady rise in adenosine monophosphate (AMP) (see Figure 2.4). This results in the activation of the enzyme AMP- Youth Physical Development (AMPK), which causes an increase in the protein PGC-1, which some have referred to as the measurer. the composition of mitochondria in

muscle. ⁹² Long-term high-intensity interval training (HVT), which involves prolonged repetitions of muscle contractions, is thought to increase intramuscular calcium concentration (Ca²⁺), which in turn activates a mitochondrial messenger system known as the calcium-calmodulin kinases. Similar to how increases in CaMK cause a rise in PGC-1, As a result, as shown in Figure 2.8, HVT and HIT seem to have comparable downstream targets but dissimilar identification mechanisms. Consequentially, ⁹³ suggests that either HVT, HIT, or a combination of the two may be used to achieve the improved fat oxidative potential, increased glucose transport ability, and high mitochondrial oxidative capacity in the skeletal muscle of endurance athletes.

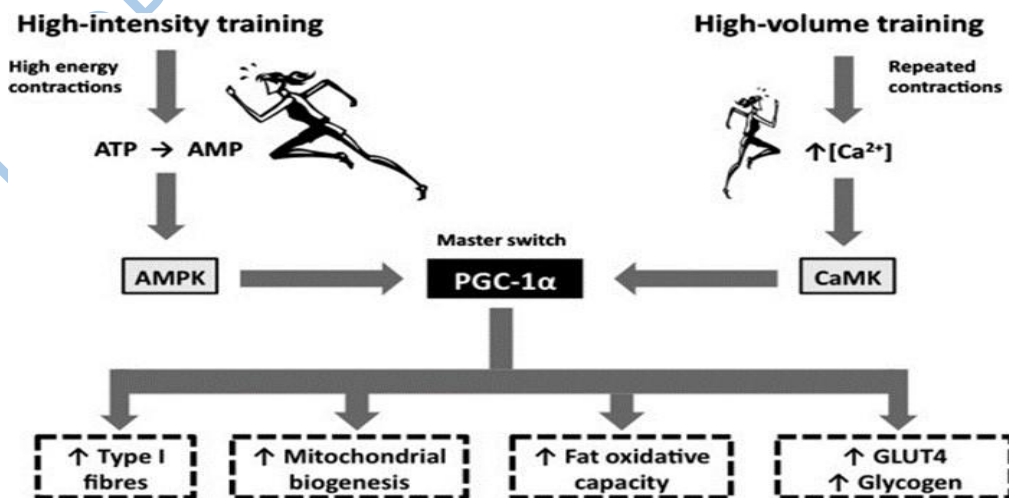


Figure 2.8: HIT and HVT's molecular pathways, as proposed by ⁹⁴ Abbreviations: Adenosine triphosphate, or ATP AMP, adenosine monophosphate; AMP-activated protein kinase, or AMPK; Molecular calcium concentration (Ca²⁺); Calcium-calmodulin kinase (CAMK); PGC-1 stands for peroxisome proliferator-activated receptor Y coactivator 1 and GLUT4 stands for glucose transporter.

2.1.6 Historical overview of exercise testing

The use of exercise in investigating physiological function can be dated back to the first modern Olympic in 1896, when the athletic feats- were observed and specific training Programmes were devised to foster improvements in either muscle hypertrophy and strength or endurance ⁹⁵. Such observations formed an advanced field of enquiry, which eventually led to the development of a new science called 'Physiology of Exercise' or according to others 'Exercise Physiology'. Originally, the purpose of all investigations in this field was to identify way to develop overall fitness, prescribe training exercises for fitness and sport and clarify matters relating to personal health and hygiene ⁹⁶. During the first three decades of the 20 century a large part of research was devoted to the study of the body's responses to exercise and outstanding contributions

were made to the science exercise physiology. 'For example, the study of oxygen consumption during exercise ^{97, 98}. and the development of indirect calorimetry set the basis for the establishment of fundamental concepts, such as maximal oxygen uptake (V_{O2}max) and energy expenditure. The formation of the Harvard Fatigue Laboratory ⁹⁹ promoted the scientific study of the effects of exercise on the human body. The research produced in this laboratory had

tremendous impact upon the study of metabolism during exercise and the effects of ageing on human performance¹⁰⁰.

For the past thirty years at least, there has been increased effort to optimise performance in the different sports. Participation has evolved from a frivolous activity to a profitable profession. As a result, the objective of research in physiology of exercise has, in some instances, been to identify formulae for success through exercise testing. Assessments of physiological responses to exercise in the 'field' have presented several limitations, which have mainly been associated with the continuous movement of the athlete. The need for assessment and close monitoring of athletic performance in a controlled environment led to the development of laboratory-based equipment, such as exercise ergometers (ergo = work, meter = measurement; ¹⁰⁰ that can be used for the sporting activity whilst manipulating exercise intensity.

The most commonly used ergometers in a sporting context are the cycle ergometer and the treadmill (running ergometer). Due to the 'specificity of training' principle ¹⁰¹, this type of equipment should only be used to assess physiological responses to exercise in athletes whose sporting activity involves cycling or running. In swimming, the difficulty of conducting physiological assessments in water led to the development of different types of ergometers. Initially, the focus of research was upon developing water-based ergometers, such as the swimming flume and the tethered swimming and the measurement of active drag (MAD) devices. Recently, there has been an increased interest in using laboratory based ergometry to assess physiological measures of swimmers. One example of laboratory-based ergometry is the swim bench, which was initially developed to be used in strength training of swimmers.

One main advantage of laboratory-based ergometry is associated with the ability to regulate and quantify exercise intensity externally. When controlling exercise intensity, metabolic responses can be compared between different individuals and at various levels of physiological function ¹⁰². In swimming, improvements in swimming performance offer little explanation of the underpinning adaptations in physiological mechanisms. Laboratory-based ergometry, such as the swim bench offers the attractive opportunity of relating physiological measures to exercise intensity. This opportunity may not directly explain swimming performance, but may be used to monitor the improvements in the power output of the upper body of swimmers. It has been shown previously that improvements in swimming performance are associated with increased power output of swimmers as measured using swim bench exercise ¹⁰³

Research in physiology of swimming

Research in the physiology of swimming has a history that originates in the first decade of this century ¹⁰⁴, yet the understanding of physiological responses to swimming has lagged behind that of other sports, such as cycling or running. This has been due, largely, to difficulties in assessing physiological measures during swimming itself. In particular, these difficulties have hindered the continuous measurement of physiological variables, such as oxygen uptake, blood lactate and power output during swimming. Despite the limitations, a considerable body of knowledge swimming physiology has been made available to swimmers and coaches. This has resulted from theoretical ingenuity, such as the estimation of oxygen uptake using a technique called 'backward extrapolation', where postexercise oxygen uptake is measured in recovery immediately after

maximal swimming ¹⁰⁵. Practical ingenuities have mainly included the design of appropriate ergometry to circumvent the problems arising from physiological assessment in the swimming

pool. One example of such ergometry is the swimming flume, which has been designed to provide an alternative testing environment for physiological assessments, whilst simulating the conditions of a swimming pool. Other ergometry, such as the swim bench, has been primarily designed for training purposes, but has equally been used in physiological assessment of swimmers¹⁰⁶.

2.1.7 Swimming Endurance and Speed

Endurance is one of the most important elements to be considered in a number of competition sport capacity¹⁰⁷. It is an essential prerequisite for swimming performance¹⁰⁸. Endurance is the ability of swimmers to perform mechanical work over a longer period of time, thus delaying the depletion of the energy supplies available in the muscle cells¹⁰⁸. The body gradually diminishes the effects of the residual substances accumulated as a result of tissue metabolism, through the buffer systems and the mechanisms for the removal of effort-induced catabolites¹⁰⁸. The improvement of endurance is linked with an increase with the number of mitochondria and with the higher oxidative capacity of the muscles¹⁰⁹. A total novice or a seasoned elite-level competitive swimmer needs a strong foundation in swimming endurance. Even sprint or short-distance swimmers might benefit from increased endurance in the water. Swimming endurance is defined as the capacity to keep applying effort against a resistance for an extended period of time. The water would be the resistance in the event of swimming.

In summary, swimming endurance may be improved by completing longer and more strenuous swim sessions. Before attempting to enhance swimming endurance, beginner's should understand the basic swimming technique for all strokes. You're ready to start developing your swimming endurance once you've mastered the basic swimming technique.

- **A stronger heart and lungs are possible with higher levels of cardiovascular exercise.**

The heart is considered a muscle. When you exercise to improve your swimming endurance, you are also boosting your cardiovascular fitness.

Heart and lungs will get stronger and more effective at performing their tasks as a result of this. That is, blood circulation and oxygen absorption from the air.

More oxygen-rich blood can be pushed through your body as your heart and lungs get stronger and more effective. More oxygen and nutrients will now be delivered to your muscles than previously. Athletic performance will improve as a result of the improved oxygen and nutrition delivery to muscle tissue. Your muscles will be able to work harder for longer periods of time due to improved oxygen levels, allowing you to swim faster over the course of a race. It's crucial to note that this doesn't happen overnight after completing one or two swimming endurance workouts; it takes time and continuous swimming training.

Swimming Speed

Speed on the other hand is the distance travelled per unit of time. This is the rate at which an object is moving in an interval of time and this can be determined as the distance travelled by the object divided by the duration of the interval¹¹⁰. Swim speed is the rate at which a swimmer is able to swim a given distance¹¹¹. Swimmers usually want to swim fast or swim more efficiently at some point. To swim fast means completing a set distance in less time¹¹². Swimming more efficiently means completing a workout or a race distance in the same amount of time but at a lower energy cost. An increase in swimming speed requires a corresponding increase in the applied muscle force¹¹².

As indicated earlier, swimming performance is a multi-factorial phenomenon involving energetics, biomechanics, hydrodynamics, anthropometrics and strength parameters ¹¹³. Hence, in order to obtain high-performance results in swimming, there is need to review the training concepts taking into consideration the parallel approach of all training elements ¹¹⁴.

Increased Swimming at a faster pace for longer periods of time.

This is related to the first point. You will be able to physically perform better for longer periods of time if you have more oxygen reaching the muscle tissues throughout your body.

Your muscles will demand more oxygen and nutrients to create energy while participating in a swimming race, a hard training set, or just attempting to push your body to its limits.

Your heart and lungs will now be stronger as a result of enhanced cardiovascular fitness. As a result, they'll be able to provide more oxygen and nutrients to the mitochondria cells in your muscles. The mitochondria cells are in charge of energy production, and they need oxygen and nourishment to accomplish so.

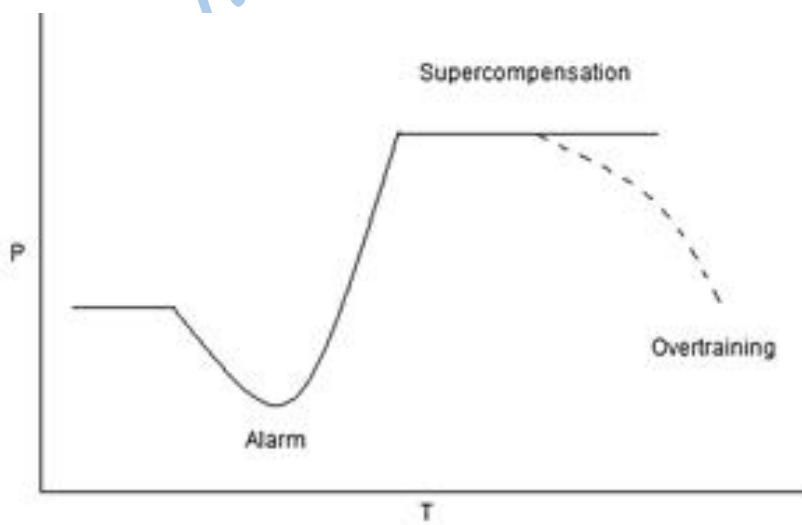
They will be able to create energy more quickly because your heart will be able to feed them with more oxygen and nutrients. In the end, you'll be able to swim faster since you'll be able to create more energy over the duration of a race.

2.2 Theoretical Model/Framework

2.2.1 Theory of Training Adaptation

To understand training practices in any field, one must first have a firm grasp of fundamental training theory. Throughout the planned process of training, the athlete is subjected to stresses that vary in volume, intensity, and frequency in addition to being broken up by rest and recovery

intervals. In order to promote training adaptation, training aims to enhance performance by progressively and methodically increasing training stressors (such as volume, intensity, and frequency of training)¹¹⁵. A well-liked theory of training adaptation is the general adaptation scheme (GAS), which was first proposed by Hans Selye¹¹⁶ and is depicted in Figure 2.9. According to the GAS theory, a training stressor occurs in an early alpha phase that generates soreness, stiffness, and fatigue, which lowers performance (P)¹¹⁷. The resistance phase eventually began as a result of the alarm phase's gradual activation of adaptable mechanisms. During the retention phase, the body may undergo beneficial modifications that either bring it back to its initial homeostasis or restore it to a new, more suitable state (i.e. supercompensation)¹¹⁸. However, if the appropriate training volume or intensity is too high to recover from, or if the amount of training stress is excessive, the exhaustion stage may emerge, which can lead to overtraining¹¹⁹.



Abbreviations: P, performance; T, time.

Figure 2.9: General adaption syndrome (GAS) as described by Hans Selye, modified by ¹²⁰

In the literature, other hypotheses that are comparable to those of training adaptation have been put out, such as Yakovljev's theory of fatigue recovery and adaptation.¹²¹ According to the stimulus-fatigue-recovery-adaptation theory, tiredness builds up proportionally to the intensity and duration of a stimulus, then dissipates during rest, leading to supercompensation. Training regimens must be based on the prevailing energy systems, skills, and motor abilities required by the sport as the degree of training adaption is extremely particular to the type of training being conducted ¹²². According to the principle of training efficiency, training adaptations only happen in muscle fibers that have been worked during the training program; therefore, the more closely the training program resembles the requirements of the desired outcome (such as enhancing performance in the 50-meter sprint or 200-meter freestyle, for example), the better the outcome will be ¹²³. For sprint to middle distance events (such as the 50, 100, and 200 m), which frequently take less than two minutes and twenty seconds at the highest level, it has been advised that competitive swimmers imitate the conventional High Volume Training (HVT) concepts. According to David Côté, one of the first experts to examine this issue, it is unclear how swimming for 3 to 4 hours per day at a rate that is noticeably slower than competitive pace will prepare the swimmer for the supramaximal exertion of competition. Leading swimming instructors and researchers have expressed similar worries about HVT ¹²⁴.

Swimming training regimens that strive to uphold the principle of specificity, like HIT or Ultra-Short Race-Pace Training (USRPT) programs, have recently become more popular¹²⁵. Extremely rapid racing pace High-intensity swimming is referred to as training when it is done in

sets that correlate to a person's best finishes in their races and entails several repeats over a small distance with brief pauses, typically no more than 20 seconds¹²⁶. A USRPT program may benefit

by being better adapted to the physical, mechanical, and mental demands of competition swimming.¹²⁷

2.3 Review of Empirical Studies

Muscle strength and power play a big role in swimming performance^{128, 129}. Upper-body muscular strength and swimming power have been shown to be associated with swimming velocity using a variety of testing equipment^{130,131}. As a result, increased arm strength may lead to increased maximum force per stroke and, as a result, increased swimming speeds, particularly in sprint lengths¹³².

Dry-land strength training¹³³ attempts to raise maximal power outputs by overloading the muscles utilized in swimming. It may also improve swimming technique. If these two points of view are accurate, then increasing physical strength will help to swim faster. The findings of the existing tests, however, are still inconclusive^{133, 134}.

2.3.1 The Physiological and Biomechanical Demands of Swimming

The Physiological Demands of Swimming

The physiological demands of swimming events involve varying contributions of the alactic-anaerobic, lactic-anaerobic and aerobic energy system with the specific contributions depending on the distance and duration of the event¹³⁵. Quantifying the precise contributions of each swimming event's energy system is challenging because of the vast range of competition distances and stroke styles. The difficulty of recording maximum oxygen consumption (VO₂max)

and heart rate while submerged are another methodological issue with physiological testing in aquatic sports.

In cyclical occurrences, atmospheric energy supply dominates the total energy requirements after about 75 seconds of maximal exertion, according to a review research on the energy system contributions during maximum exercise. To determine the contributions of each energy system, most studies used trained athletes to perform a variety of durations of maximal effort exercise, usually by monitoring the accumulated oxygen deficit (AOD). The AOD is a measurement of anaerobic capacity because it represents the link between submaximal work intensities and oxygen consumption, which is used to lower the maximum amount of energy demand. The AOD is a measurement of anaerobic capacity because it represents the link between submaximal work intensities and oxygen consumption, which is used to lower the maximum amount of energy demand. The findings concur with a number of investigations by Duffeld and associates¹³⁷. Since the 200-meter swim normally lasts around two minutes, it might be argued that races 200 meters and higher should rely more on aerobic energy supply. Numerous studies have examined how the energy system affects young swimmers' and other older swimmers' performance in 200-meter swimming competitions¹³⁹. The energy system contributions were calculated using measurements of the maximum oxygen consumption (VO₂max) and peak blood lactate concentration (BL_{peak}) while swimming. Young swimmers (aged 14.5-19 years) devote 71.1% of their aerobic energy to 200-meter swimming competitions, whereas other older swimmers contribute between 63 and 65.9%, according to the findings of this research. Events shorter than 200 meters (50 and 100 meters) appear to be more dependent on anaerobic and lactic energy sources because they last just 75 seconds, but races longer than 200 meters (200, 400, 800, 1,500, and 10,000 meters) are more dependent on aerobic energy

sources. Numerous studies have examined how swimmers' performance is influenced psychologically. The critical velocities, blood lactate peak, and peak oxygen consumption ($\text{VO}_{2\text{peak}}$) were the physiological measures that were

most commonly used in these research. The largest amount of oxygen absorbed during an exercise test up until exhaustion is known as peak oxygen consumption. It is a typical measure of aerobic fitness in a variety of sports. The standard method for measuring swimming $\text{V-O}_{2\text{peak}}$ is to use a respiratory snorkel connected to a portable gas analyzer during a maximum effort time trial or incremental test, or to use the backward extrapolation technique immediately after the swim to collect exhaled gases from the swimmer using a portable gas analyzer or DOUGLAS bag during the first 20 seconds of post-swim recovery.¹⁴⁰ Peak blood lactate concentration, which is measured post-exercise at specified times and has been used as a metric of anaerobic capacity, is the total or peak blood lactate value. The highest speed that can be maintained without exertion is known as crucial velocity, and it is used as a gauge of aerobic capacity. The slope of the reaction line on the distance time plot, which is established between at least two swimming distances, such as 200 and 800, is used to calculate critical velocity. A simpler method for calculating velocity, however, was recently created using a single 400-meter time trial at maximal exertion¹⁴¹.

$\text{VO}_{2\text{peak}}$ and BL_{peak} , which are measured while swimming, and performance were found to account for 45.2% of a 25 young swimmers' (15.2 1.9 years) 100-meter performance in a study of the physiological factors influencing 100-meter performance. Similar studies showed that $\text{V-O}_{2\text{peak}}$ was measured instantly during post-swim and predicted 35.8% of 400 m performance in 15 swimmers who were in their pre-pubescent years (11.9 0.3 years) and 14

swimmers who were in their post-pubescent years.¹⁴² This is an unexpected outcome given that longer swimming events, like the 400 m, frequently have higher aerobic energy requirements. Therefore, it would be expected that, compared to the 200 m, $\dot{V}O_2$ max would be a better predictor of performance. Similar findings were made regarding the variable "velocity" as a measure of "aerobic capacity," which was found to only account for 34% of 100-meter performance over the course of 24 years

of swimming (13.0 ± 0.7 years)¹⁴³. While biomechanical assessments are regularly reported to be one of the strongest predictors of swimming performance, commonly used physical metrics such as $\dot{V}O_{2peak}$, BL_{peak} , and $Cv_{velocity}$ do not appear to be effective predictors of swimming performance¹⁴⁴.

2.3.2 The Biomechanical Demands of Swimming

Unlike swimming, which uses force against the water, land-based sports require the application of force against the ground in order to go forward. After that, swimmers may accelerate their bodies forward by pushing their arms backwards against the resistance of the water, similar to how a runner accelerates forward by pushing backward on the ground. However, because water is a fluid, it gives way under pressure, unlike the ground, which does not support runners. As more time is spent practicing or training, there may be more opportunities to develop the difficult skill of exerting force against a fluid medium, which coaches often refer to as "feel" for the water. This could work against the traditional HVT approach in swimming¹⁴⁵.

The ability to maximize forward motion through the water while minimizing backward movement resistance is a prerequisite for good swimming performance. Propelling occurs as a result of the propelling forces (F_p) produced by the arms and legs during the swimming stroke,

as depicted in Figure 10. A swimmer will encounter resistive or drag forces (F_d) because water has a significantly higher density than air when moving forward. Drag or resistive forces operate in the opposite direction to propulsive forces; see Figure 2.10.¹⁴⁶

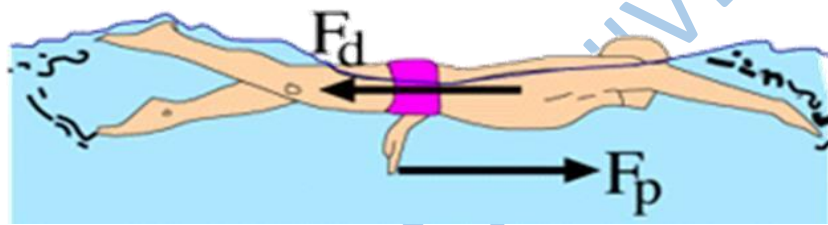


Figure 2.10: During forward motion, swimming success depends on the capacity to increase propulsive forces (F_p) while decreasing resistive or drag forces (F_d)¹⁴⁷.

Frictional drag (the resistance produced between the water and the swimmer's skin), form drag (the resistance produced by the swimmer's profile in the water), and wave drag are the three main elements that influence a swimmer's resistance or drag (the resistance created by waves when swimming at or near the surface). In order to accelerate, a swimmer must put forth a rate of exertion each stroke equivalent to the power necessary to overcome water resistance. If a swimmer can't produce F_p larger than the F_d acting on them, they will swim at their fastest possible pace¹⁴⁸. The importance of a swimmer's biomechanical or technical ability to produce F_p

while minimizing F_d , which is directly tied to the physiological demands, is underlined as the reason swimming performance is largely dependent on this. ¹⁴⁸

The biomechanical metrics stroke rate (SR), stroke length (SL), and stroke index (SI) have been repeatedly demonstrated to be among the best predictors of swimming performance in young swimmers ¹⁴⁹. The number of swimming stroke cycles accomplished in a minute is known as stroke rate, which is determined by timing three stroke cycles with a manual chronometer. The distance covered by a swimmer during each stroke cycle is known as stroke length and is determined by

dividing swimming velocity (SV) by stroke rate (SR). The stroke index was first calculated by dividing SV by SL and was initially set at ¹⁵⁰, which represented the swimmer's stroke efficiency. In a study by ¹⁵¹ researchers, SR, SL, and SI, they determined that 25 competitive young swimmers (15.2 ± 1.9 years) performed 90.3% of 100 meters' freestyle. 15 pre-pubertal swimmers (11.9 ± 0.3 years) and 14 post-pubertal swimmers (14.3 ± 1.4 years) had 400 m freestyle performances that were assessed to be 89.8% accurate in a study by ¹⁵² researchers who discovered SR, SL, and SI. In a larger cohort of 46 young swimmers with ages ranging from 10 to 17, ¹⁵² reported comparable results. We found that between 97 and 99% of the performance for the 100 m, 200 m, and 400 m could be predicted accurately by SR, SL, and SI. Surprisingly, SI alone found that 87-90% of performances on the 100, 200, and 400 meters were accurate. Senior swimmers have been found to have higher body mechanical characteristics like SL and SI than swimmers of lower caliber, despite the fact that many of these studies were performed on young swimmers.

2.3.3 Relationship Between Dry-Land Strength/Power Assessments and Swimming Performance

The ultimate goal of a competitive swimmer is to cover a distance in the shortest amount of time possible. As a result, the number of strokes performed decreases as the distance to be swum decreases. Strength has therefore been identified as one of the key multi-factorial factors that may increase swimming velocity for shorter competition distances¹⁵³. Furthermore, when comparing technical characteristics with strength, it is expected that as the distance decreases, strength role rises^{154, 155, 156}.

In the last three decades, isokinetic and isometric strengths have been used to assess strength and power in dry land.¹⁵⁷ This analysis was shown to be beneficial in determining how much swimming performance is influenced by various variables, as well as in improving training regimens. A study on 22 female and 18 male swimmers found that arm muscular power measured on a biokinetic swim bench is significantly correlated with 25 yard front crawl swimming velocity ($r = 0.90$). Experiments on a bike ergometer utilizing simply arms supported the latter findings.¹⁵⁸ Astudied the upper body anaerobic power of 30 age-group swimmers (14 men and 16 females), finding moderate-high correlations between peak power, mean power, and fatigue index and 50-meter swimming velocity ($r = 0.82, 0.83, \text{ and } 0.41$, respectively). Furthermore, the same study group¹⁵⁸ found that leg power indices did not improve estimate of 50-meter swimming performance, and that arm power is essential in longer swim competitions (400 m)¹⁵⁹. Other research backs up these findings.^{160,161} However, the validity of the relationships appears to be skewed in the research mentioned above due to the use of diverse samples in terms of age, gender, and perhaps maturation. In the sport of swimming, skepticism

about the results reached by diverse groups has long been acknowledged ¹⁶². Furthermore, the usage of a biokinetic swim bench or a cycle ergometer that solely uses arms ignores the relevance of lower limbs and body roll in body coordination.

Dry-land strength training may have beneficial benefits on work economy through many processes (e.g., enhanced reflex potentiation, changes in the synergists) ¹⁶³. Furthermore, dry-land strength training is a popular technique in swimming training, despite the lack of scientific proof. ¹⁶⁴ In fact, only a few research have looked at the relationship between strength training force parameters (e.g. bench press) and swimming performance. ¹⁶⁵ tested 29 male swimmers with ages ranging from 14 to 22 years old and 25 yard swimming velocity on one repetition of maximal bench press (results not provided in study) (ranging from 1.72 to 2.31 m. s-1).

This measure of dry-land strength, according to these scientists, did not add much to the prediction of sprint velocity. It should be noted that the age range should be considered, especially when major changes in somatotype occur within this range. ¹⁶⁶ found a moderate but significant association between 6 maximum bench press repetitions and swimming performance (both 25 and 50 m performance times; -0.58 ; $p 0.01$) in young competitive swimmers using a more homogeneous population. ¹⁶⁷ were the only writers that measured strength characteristics using additional workouts, to our knowledge. For male and female swimmers, they tested one maximum repetition in bench press, lat pull down, and triceps press. Although significant connections were found between the three workouts and tethered swimming forces, only the lat pull down for the female swimmers group ($r = 0.64$, $p 0.05$) showed significant correlations with swimming performance.

The research mentioned above only looked at the maximum load that swimmers could obtain at maximum repetitions, which is more closely linked to maximum force than explosive force ¹⁶⁷ used a velocity linear wire encoder to quantify the power generated in bench press maximum velocity repetitions to overcome these constraints. The authors reported that there was a moderate connection between maximal bench press strength and swimming power ($r = 0.63$), however they did not provide the r value for swimming velocity. This is a starting step toward novel strength-training ideas, implying that additional research is needed.

In conclusion, the contradictory results of previous tests show that the relationship between dry-land strength and swimming ability is still unknown. More research is needed, with the following objectives: (i) evaluating homogeneous groups of subjects; (ii) assessing strength/power parameters in more strength exercises with muscular solicitations similar to swimming movements; and (iii) investigating which parameters (e.g. one maximum repetition or velocity

displacement) are more appropriate to explain variation in swimming velocity. Further research into the function of muscular strength and/or power in swimming performance may be possible.

2.3.4 Effects of Strength Training on Swimming Performance

Swimming requires a ideal degree of strength and power since it is based on maximizing the capacity to create propelling forces while minimizing the resistance given by the liquid environment ¹⁶⁸. Strength training regimens are therefore a widespread practice among swimmers ¹⁶⁸, despite the fact that their benefits are debatable in specialist literature ¹⁶⁸. Furthermore, many coaches believe that strength training may induce an increase in muscle bulk (hypertrophy) or a reduction in flexibility, both of which would severely impair swimming

performance and increase drag forces ¹⁶⁹. As a result, two assumptions emerge: (i) a dry-land strength training program has many components, and improving power is undoubtedly one of the most essential ¹⁷⁰; and (ii) the exercises chosen should be congruent with the types of movement required in swimming ¹⁷¹.

To the best of our knowledge, few investigations have been conducted on the impact of strength training regimens on swimming performance enhancement. ¹⁷² found increases in muscular strength of 20 to 40% in adult swimmers (n = 10) after a strength program utilizing free weights in one of the first trials. These gains equated to a 4.4 to 2.1 percent increase in performance in the 25 and 50 meter freestyle, respectively. ¹⁷³), on the other hand, questioned whether strength developed on land could be favorably transferred to propulsive power utilized in water, because the specialization of training seemed to differ. These researcher's used weight lifting machines and free weights to do a strength training Programme three times a week for eight weeks. It was revealed that, there was a 25 to 35 percent increase in muscle strength, but this did not equate to an improvement in swimming performance. ¹⁷⁴ These mixed results suggested that further research

was needed to determine the amount of muscle strength development needed to improve swimming performance.

Three studies published lately looked into the impact of dry-land strength training on swimming ¹⁷⁵. used a dry-land strength Programme twice a week (45 minutes each session) for 12 weeks with an intensity of 80 to 90% of maximum load; ¹⁷⁶ used 1 to 3 sessions per week for 11 weeks with the heaviest load possible at each session; and ¹⁷⁷ used a strength training regimen twice a week for 8 weeks with the heaviest load possible at each session. Second, the

intervention group ranged from $n = 7$ ¹⁷⁸ with male and female swimmers (16.5 2.5 years old), $n = 11$ with 6 boys and 5 girls (17.5 2.9 years old), and $n = 12$ with 8 boys and 4 girls (12.0 0.78 years old). Although boys and girls acquire strength at equal rates throughout preadolescence, following puberty, boys have greater muscle strength levels than girls, which might lead to misinterpretation of) and¹⁷⁹. Finally, in a 25-meter pool, swimming performance was assessed following a warm-up of unknown length or 2000 meters, in-water starts, or diving starts.¹⁸⁰ Warm-up effects are debatable, although they may impact swimming performance, particularly in short distances with high effort¹⁸¹. Furthermore, diving, glide, and turns all contribute to total performance, which may be taken into account when evaluating swimming ability. Despite the limitations, these studies show that combining swimming and dry-land strength training improves 50 m and 400 m freestyle performance more effectively than the swimming program alone. Although it has not been demonstrated in prepubescent swimmers, strength training appears to improve swimming performance in the 25 and 50 meter freestyle¹⁸²

2.3.5 Challenges to Health and Well-Being for the Youth Athlete

Due to serious worries about physical inactivity, childhood obesity, and its connection to the growth of chronic diseases like cardiovascular disease and diabetes, modern youth's health, fitness, and well-being are currently hot subjects. Maintaining youth participation in sport is essential, but there are many challenging challenges to overcome. High training loads in swimming can lead to early sport specialization, overuse injuries, and overtraining syndrome in young athletes⁸⁴. Intensive year-round training in one sport to the exclusion of other sports is

how early sport specialization is defined ¹⁸⁵Young people who participate in year-round training (more than eight months per year), choose one primary sport, and put all other sports on hold in order to focus on that one major activity are considered to have early sport specialization. According to anecdotal evidence, it is rather typical for young swimmers to achieve all three requirements, therefore it may not be surprising that athletes as young as 14 have won Olympic medals (Kyoko Iwaak of Japan won the 200 m breaststroke in the 1992 Summer Olympics in Barcelona, for instance). Early competition is also typical in activities like figure skating, diving, and gymnastics ¹⁸⁶.

Young swimmers with talent usually swim far faster than their more seasoned and senior level rivals, and swimming success at a high level at a young age is not uncommon. This could be as a result of the swimmer's biomechanical profile having a significant effect on their swimming ability¹⁸⁷. Because of this, a highly skilled young swimmer with high propelling force and low resistance or drag force (due to a smaller body form) can swim at a faster pace than an experienced swimmer with the same propelling force but higher resistance or drag force (due to a larger body shape) (see 2.3 The biomechanics of swimming). Due to the frequently confined space available in public swimming pools (i.e., the talented young swimmer won't be able to swim in a line with their peers), this poses various demands on swim coaches. As a result, gifted young swimmers are

frequently quickly promoted to senior teams where the volume and frequency of training are significantly higher, leading to early specialization. Young people should avoid early sport specialization, according to research, as playing multiple sports frequently improves motor skill

development, boosts athletic ability, and increases the possibility that a young person will find a sport they enjoy and may thrive in¹⁸⁸.

Early sport specialization is also associated with a higher risk of injury in young athletes¹⁸⁹. In 2011, competitive youth athletes (13.7 1.6 years old) in 18 different sports participated in a study by 190 persons to examine the association between sport specialization and injury history. In contrast to less specialized athletes, the results showed that highly specialized athletes were more likely to report an overuse injury ($p = 0.01$). If they participated in a major sport for more than eight months out of the year, those athletes were more likely to report an upper extremity overuse injury ($p = 0.04$) or a lower extremities overuse injury ($p = 0.001$). If they played their primary sport for more hours per week than their age, athletes were more likely to report any kind of injury ($p = 0.001$). Due to the repetitive and overhead nature of swimming, athletes are frequently more likely to sustain an injury. This is especially true when highly specialized training and competition are conducted at a young age.¹⁹¹

In competitive young swimmers (15.9 2.7 years) with a weekly swim training volume of 16 hours or 40 kilometers, the association between training methods and shoulder impact was investigated. The amount of weekly swimming time ($r_s = 0.39$, $p = 0.005$) as well as the number of kilometers (km) travelled each week ($r_s = 0.34$, $p = 0.01$) were found to be strongly correlated with the occurrence of shoulder impairment.^{192, 193} 102 competitive young swimmers (15.1 1.4 years old) with a weekly swimming distance average of roughly 41 km were studied for attitudes and behaviors toward shoulder pain. 72 percent (73/102) of the swimmers acknowledged to using

medicines in the year prior to help them exercise and manage their shoulder pain. Swimming while experiencing severe shoulder pain and the idea that severe shoulder pain is normal were discovered to be significantly correlated ($\chi^2(85) = 0.552, p = 0.0005$).¹⁹⁴ concluded that competitive young swimmers think shoulder pain is normal and should be tolerated in order to finish the necessary training volume. Overtraining syndrome could also develop as a result of the increased pressure for specialized training and competition (OT).

Overtraining syndrome is characterized as an accumulation of stressors, both training-related and unrelated, that impairs performance at predetermined levels and can endure for several weeks to months. Mood disorders, greater exertion during practice and competition, lack of appetite, sleep problems, and an increase in upper respiratory tract infections are all typical symptoms of OT.^{195,196} the frequency of OT in 376 young athletes participating in 19 different team and individual sports (15.1 \pm 2.0 years). 110 young athletes (29%) said they received occupational therapy at least once while competing. Individual sports (such as swimming, diving, golf, etc.) and those with a greater level of competition (such as those with national and international level competitors) had a much higher prevalence of OT ($p = 0.01$).¹⁹⁷ studied the prevalence of OT in 231 young swimmers between the ages of 14.8 and 1.4 from four different countries. Sixty (34.6%) of the young swimmers in the entire sample claimed to have experienced OT at some point in their swimming careers, with a mean of 2.7 \pm 1.4 symptoms. The most OT (75%) was reportedly experienced during the most challenging training sessions. Having faster 100 m personal best times than the swimmers without OT made the OT swimmers more competitive ($p = 0.01$). Young athletes who compete at a high level and often undergo more specific training at a young age in individual sports, like swimming, appear to be at a greater risk of OT. In particular, for young swimmers, this may lead to early exercise cessation and

psychological burnout.¹⁹⁸ Encourage a more all-encompassing strategy for training your athletes. Training plans should include a variety of possibilities, including those for increasing stamina, improving movement competence, encouraging creativity, and enhancing enjoyment through games and unstructured play. However, given the present swimming training hours for this club, which are typically over 16 hours per week, it is challenging to understand how these chances for young swimmers' holistic athletic development can be established in the current environment. Consistently, this group is prone to health and wellbeing problems such as early sports-related overuse injuries¹⁹⁹, overtraining syndrome²⁰⁰, and early puberty²⁰¹. Any viable strategies for lowering the amount of swimmer training currently being done (like HIT) should be evaluated in order to incorporate these holistic features into a swimming training programme.

2.4. Conceptual Model/Framework

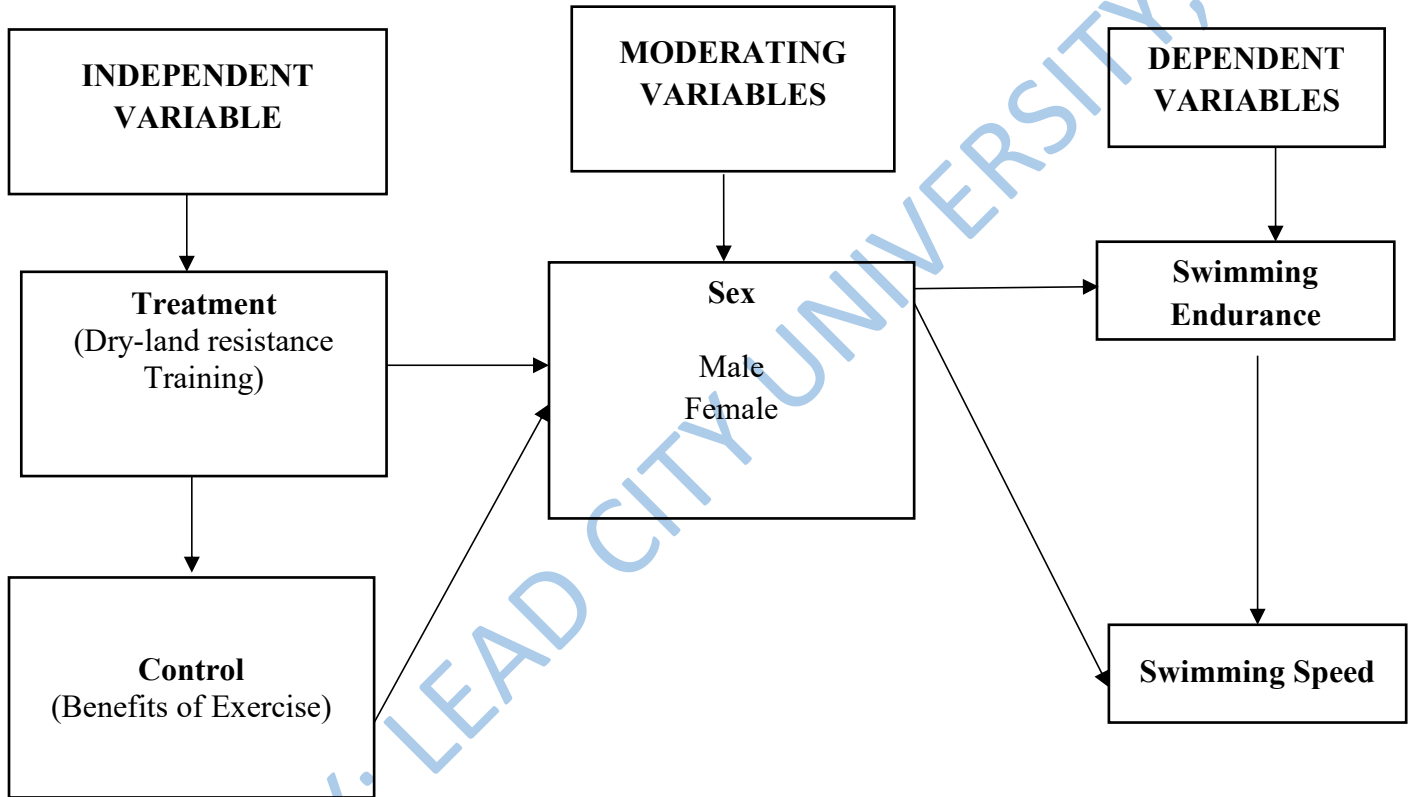


Fig. 2.1: Conceptual Framework of Effect of 6-Week Dry-land Resistance Training on Swimming Endurance and Speed of Lead City International School Swimmers, Ibadan

Source: Field survey, 2022

2.5 Summary of Gap in Literature

In order to develop the swimmer's ability to improve performance, swimming in a competitive pool creates a demanding training environment in which all four phases of the race are handled. Optimizing the physical requirements within the four stages of a competitive pool race necessitates addressing the demands of strength and power dry-land training as well as aerobic and anaerobic in-pool training. The leg extensor force-time curve features used in the turn phase of pool racing have not received much research. When only minor performance adjustments in elite swimmers can be achieved across a competition year, knowing which leg extensor force-time curve features have a bigger performance influence on the overall speed of the turn phase and how they may be improved becomes increasingly essential.

The swim and S&C coaches can choose which phases to prioritise and when in the training plan by having a thorough understanding of the stages of a competitive pool swimming race as well as expected performance changes over the course of a competitive year. Once the coaching staff has determined which leg extensor force-time curve features during the turn phase are executed at greater levels by elite level swimmers, they can train these characteristics at an earlier age or with a higher emphasis within the training schedule. Few research has looked at the leg extensor force-time curve features utilized during the turn phase, and none have looked at whether training modality within a concurrent training setting improves these qualities the most. This knowledge may then be used to the prioritization of training in order to improve primary leg extensor force-curve characteristics, turn performance, and eventually overall race performance.

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Chapter Three

Methodology

The techniques and strategies used to acquire data are described in this chapter. It is designed to include the following services:

- 3.1 Research Design
- 3.2 Population of the Study
- 3.3 Sample and Sampling Techniques
- 3.4 Description of the Research Instrument(s)
- 3.5 Validity of Research Instrument
- 3.6 Reliability of the Research Instrument
- 3.7 Data Collection
- 3.8 Data Analysis

Endnotes

3.1 Research Design

The randomized pretest-posttest control group experimental research design using matched participants with a 2x2 factorial matrix was adopted for this study. The design employed two groups of participants which were designated, experimental and control groups.

Table 3.1 The design outline is presented as follows:

Experimental Group:	O₁	Mr	X₁	O₂
Control Group:	O₃	Mr	X₂	O₄

Where:

O₁ and O₃= Pre-test of the experimental and control groups respectively

M = Matching

r = Randomization

X₁= Treatment (Dry-land resistance Training)

X₂= Placebo (Benefits of exercise lesson)

O₂ and O₄ = Posttest of the experimental and control groups respectively

Table 3.2 Breakdown of the Factorial Matrix

Independent Variables	Moderating Variables	Dependent Variables
1. Experimental (Dry-land resistance training)	Sex	Swimming Speed
	<ul style="list-style-type: none"> • Male • Female 	Swimming Endurance
2. Control (Lesson on exercise benefits)	Sex	Swimming Speed
	<ul style="list-style-type: none"> • Male • Female 	Swimming Endurance

3.2 Population of the Study

The population for this study included all male and female student swimmers of Lead City International School, Ibadan.

3.3 Sample and Sampling Techniques

The sample size for this study was Fifty-two (52) volunteer swimmers of Lead City International School. The participants were chosen using a multistage sampling techniques. The following are the phases involved in the procedure.

Stage 1: Purposive sampling technique was used to select fifty-two (52) swimmers in Lead City International School.

Stage 2: Fifty-two (52) volunteers were pretested on the dependent variables.

Stage 3: Participant were matched by swimming performance and sex and randomly assigned to each group of experimental (26) and control (26).

Inclusion and Exclusion Criteria

Participants were swimmers from Lead City International School Ibadan. The training programme was open to everyone who submitted informed consent form from parents and completed the readiness questionnaire. All participants who met medical requirements participated in the dry-land resistance training. Participants who did not submit the informed consent form were not allowed to participate.

3.4 Research Instruments

The following instruments were used for data collection.

A digital stop watch, Casio brand, made in China was used to measure the amount of time that elapses between its activation and deactivation. The stopwatch was used in timing the

participants speed and duration of exercise¹. Weighing scale: Hanna portable weight measuring scale (RA9012) made in England was used to measure total body weight of the participants in kilogram (kg). Weight was recorded to the nearest 0.1 kg². Stadiometer is an instruments used for measuring human height. It is usually attached to a wall so that the subjects can be aligned vertically in the appropriate manner, it is calibrated in centimeters³. The range of the instrument was between 60cm to 220 cm and it was used to measure participant's height to the nearest 0.1 centimeter. Sphygmomanometer, N4 1PS, made by Accosson, vale road, London, was used to measure heart rate. Inelastic measuring tape, butterfly brand, made in China, was used to measure. It consists of a ribbon with linear-measurement markings. This was used in measuring the distance covered during gliding from the wall. Sports field was used for the dry-land resistance training.

3.5 Validity of Research Instrument

Validity is the ability of a test results to reflect the accuracy of the parameters being measured. The test must be valid for an accurate score to be obtained. For this research, standardized scientific tests and instruments were used to ensure validity. The researcher and the supervisor endeavored to cross-check the workability of the instruments before use.

All the instruments that were used by the researcher for testing have been utilized by other researchers to test the various physical fitness components and have been found to be reliable.

3.6 Reliability of the Research Instrument

Reliability is the consistency with which an instrument measures what it purports to measure. The instruments for this study were standadized instrument, but for the purpose of this study the intruments were recalibrated where necessary.

3.7 Data Collection

In order to ascertain the effect of 6-week dry-land resistance training on swimming endurance and speed of swimmers in Lead City International School, Ibadan, Nigeria, standardized instruments were used to measure the swimming endurance and speed of the respondents. These are explained as follows:

Informed consent forms was handed out through each volunteer for parents to confirm of their wards willingness to participate in the study. Also participants were made to realize that they may experience some dscomfort like muscle cramps and pains at the beginning of the training. However, they were admonished not to pull out by assuring them that the pains are only some of the early effects of the training which will reduced as their bodies adapt through regular participation in the training programme. See appendix 3 for the Informed Consent Form.

Experimental group were made to go through six weeks dry-land resistance training programme three days a week, while the control group were made to undergo 20 minutes of benefits of exercise lesson for six weeks, two days a week. A normal resting heart rate for adolescent ranges from 60 to 100 beats per minute. Digital sphygmomanometer was also used to check the heart rate, so as to ensure accurate measure of the heart rate. The training programme lasted for six weeks, three sessions per week. The placement day was Mondays, Wednesdays and Fridays for experimental group, while control group were placed on placebo of benefit of exercise on Tuesdays and Thursdays. Each training session had segment of warm up, follow by main activity and ended with cool down exercises. Glucose water was given to the participants at the end of every training session, water break was also observed for participants that wishes to

rehydrate during the exercise session. The researcher with the help of three (3) trained research assistants undertook the measurement and recording of data.

Treatment Group: There was pre-test measures of the selected dependent variables (swimming endurance and Swimming speed) of the participants before random assignment to the two groups. Time was used to measure swimming speed of the participants while number of laps was used to measure the swimming endurance of the participants. Experimental group were made to go through a six (6) weeks dry-land resistance training programme three (3) days a week. After the programme, they were tested again as the post-test measures. See training programme in Appendix 1.

Control Group: There was pre-test of the selected dependent variables (swim endurance and swim speed) on the control group. They were made to undergo 20 minutes of benefits of exercise lesson) for six weeks at non-consecutive days per week. This process led to the post-test measures which was take place after the 6 weeks of training. See Appendix 2 for the programme for the Control group.

3.8 Data Analyses

Descriptive statistics of frequency count and percentages was used to analyze the demographic data of the participants while mean and standard deviation was used to determine the anthropometric compositions of the participants. Inferential statistics of Analysis of Co-variance (ANCOVA) was used to test the hypotheses formulated at 0.05 level of significance.

Endnotes

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Chapter Four

Results and Discussion of Findings

This chapter presents results of the analyses and discussion of findings. The results and discussion of findings are presented based on demographic characteristics of the participants, research question and hypotheses as follow:

4.1 Demographic Data Analysis

Sex	Frequency	Percent	Table 4.1: Distribution of the Participants by Sex
Male	26	50.0	
Female	26	50.0	
Total	52	100.0	

Distribution of the Participants by Sex

Source: Field Survey, 2022.

Table 4.1 reveals that equal number of male and female respondents sampled in this study.

Table 4.1.2: Distribution of the Participants by Age

Age	Frequency	Percent
10 years	10	19.2
11 years	8	15.4
12 years	7	13.5
13 years	22	42.3
14 years	5	9.6
Total	52	100.0

Table 4.1 reveals that 10 (19.2%) participants were 10 years old, 8 (15.4%) were 11 years, 7 (13.5%) were 12 years. Also, 22 (42.3%) respondents were 13 years old, while 5 (9.6%) were 14 years old. This means that, most of the participants were 13 years old.

4.2 Research Question

The research question below was answered:

Research Question 1: What is the resting heart rate of swimmers before and after six weeks in Lead City International School, Ibadan?

Mean and Std. Deviation	Heart Rate Pre-test score	Heart Rate Post-test score
Mean	64.1731	63.3654
Std. Deviation	2.65479	2.80076

Table 4.2.1: Distribution of the Participants by Heart Rate (Beat/Minute)

Source: Field Survey, 2022.

The result shows that the mean heart rate of the participants for the pretest stage was 64.1731, while that for posttest was 63.3654 was recorded at posttest stage. This result indicates that, pre-test heart rate was higher by 0.81 compare to that of the posttest score. This means that, there was a decrease in the heart rate of swimmers in Lead City International School swimmers.

Hypotheses

The following hypotheses were tested in this study.

H₀₁: There will be no significant main effect of treatment on swimming endurance of swimmers in Lead City International School, Ibadan.

Table 4.2.2: Summary of Analysis of Covariance of Main Effect of Treatment on Swimming Endurance (Number of laps/time) of participants

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	31526.309 ^a	2	15763.155	12716.380	.000	.998
Intercept	.886	1	.886	.715	.402	.014

Pretest	23590.198	1	23590.198	19030.577	.000	.997
Treatment	126.547	1	126.547	102.087	.000	.676
Error	60.740	49	1.240			
Total	690342.200	52				
Corrected Total	31587.049	51				

Table 4.2.2 shows that there was a significant main effect of treatment on swimming endurance ($F_{(1,49)}=102.087, p<0.05, \eta^2=0.676$) of swimmers in Lead City International School, Ibadan. The null hypothesis was therefore rejected. This implies that treatment (dry-land resistance) was effective in improving the swimming endurance of swimmers in Lead City International School.

Table 4.2.3: Estimated Marginal Means of Treatments on Swimming Endurance (Number of laps/time) of participants

Treatment	Mean	95% Confidence Interval		
	(Number of laps/time)	Std. Error	Lower Bound	Upper Bound
Experimental (Dry-Land Training)	110.811	0.232	110.346	111.276
Control (Talk on Benefits of Exercise)	114.297	0.232	113.831	114.762

The table 4.2.3 reveals that after controlling for initial difference on swimming endurance, the

participants exposed to dry-land resistance training had a lower mean score (mean=110.811), while the control had a higher mean score of 114.297. This implies that dry-land resistance training with the least mean score was more effective in relation to swimming endurance of swimmers in Lead City International School.

Table 4.2.4: Summary of Analysis of Covariance of Main Effect of Treatments on Swimming Speed (Time) of participants

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1159.948 ^a	2	579.974	1915.805	0.000	0.987
Intercept	.319	1	0.319	1.054	0.310	0.021
Pretest	1086.263	1	1086.263	3588.209	0.000	0.987
Treatment	11.230	1	11.230	37.096	0.000	0.431
Error	14.834	49	0.303			
Total	19905.005	52				
Corrected Total	1174.782	51				

Ho2: There will be no significant main effect of treatment on swimming speed of Lead City International School swimmers.

Table 4.2.4 shows that there was a significant main effect of treatment on swimming speed ($F_{(1,49)}=37.096, p<0.05, \eta^2=0.431$) of Lead City International School swimmers, Ibadan. The null hypothesis was therefore rejected. This implies that treatment (dry-land resistance) was effective in improving the swimming speed of Lead City International School swimmers.

Table 4.2.5: Estimated Marginal Means of Treatment on Swimming Speed (Time) of participants

Treatment	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Experimental (Dry-Land Training)	18.508	0.109	18.290	18.727
Control (Talk on Benefits of Exercise)	19.449	0.109	19.231	19.667

Table 4.2.5 reveals that after controlling for initial difference on swimming speed, the participants exposed to dry-land resistance training had the lower mean score (mean=18.508), while the control had a mean score of 19.449. This implies that dry-land resistance training was more effective in improving the swimming speed of swimmers in Lead City International School, Ibadan.

Ho3: There will be no significant main effect of sex on swimming endurance of swimmers in Lead City International School.

Table 4.2.6: Summary of Analysis of Covariance of Main Effect of Sex on Swimming Endurance (Number of laps/time)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	31402.468	2	15701.234	4168.135	0.000	0.994
Intercept	21.899	1	21.899	5.813	0.020	0.106
Pretest	30102.468	1	30102.468	7991.164	0.000	0.994

Gender	2.706	1	2.706	0.718	0.401	0.014
Error	184.581	49	3.767			
Total	690342.200	52				
Corrected Total	31587.049	51				

Table 4.2.6 shows that there was no significant main effect of sex on swimming endurance ($F_{(1,49)}=0.718, p>0.05, \eta^2=0.401$) of swimmers in Lead City International School, Ibadan. The null hypothesis was therefore considered tenable. This implies that sex had no impact on swimming endurance of swimmers in Lead City International School.

Table 4.2.7: Estimated Marginal Means of Sex on Swimming Endurance (Number of laps/time) of participants)

Gender	Mean		95% Confidence Interval	
	(Number of laps)	Std. Error	Lower Bound	Upper Bound
Male	112.787	0.385	112.013	113.561
Female	112.320	0.385	111.546	113.094

Table 4.2.7 reveals that after controlling for initial difference of sex on swimming endurance, female had a lower mean score of (112.320) than their male (112.787) counterpart, but the difference (0.467) was not substantial.

H₀₄: There will be no significant main effect of sex on swimming speed of swimmers in Lead City International School.

Table 4.2.8: Summary of Analysis of Covariance of Main Effect of Sex on Swimming Speed of participants (Time)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1149.773	2	574.887	1126.407	0.000	0.979
Intercept	1.256	1	1.256	2.460	0.123	0.048

Pretest	1149.730	1	1149.730	2252.728	0.000	0.979
Gender	1.056	1	1.056	2.068	0.157	0.041
Error	25.008	49	0.510			
Total	19905.005	52				
Corrected Total	1174.782	51				

Table 4.2.8 shows that there was no significant main effect of sex on swimming speed ($F_{(1,49)}=2.068, p<0.05, \eta^2=0.157$) of swimmers in Lead City International School, Ibadan. The null hypothesis was therefore considered tenable. This implies that sex had no impact on swimming speed of swimmers in Lead City International School.

Table 4.2.9: Estimated Marginal Means of Sex on Swimming Speed of participants (Time)

Gender	Mean (Time)	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Male	19.121	.140	18.840	19.403
Female	18.836	.140	18.555	19.118

Table 4.2.9 reveals that after controlling for initial difference of sex on swimming speed, female had a lower mean score of 18.836 than their male (19.121) counterpart. The difference was marginal (0.285)

H₀₅: There will be no significant interaction effect of treatment and sex on swimming endurance of swimmers in Lead City International School

Table 4.2.10: ANCOVA Analysis of Interaction Effect of Treatments by Sex on Swimming Endurance of participants (Number of laps/time)

Source	Type III Sum	df	Mean Square	F	Sig.	Partial Eta
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	of Squares				Squared	
Corrected Model	31532.862	4	7883.215	6837.580	.000	.998
Intercept	.323	1	.323	.281	.599	.006
Pretest	22150.523	1	22150.523	19212.461	.000	.998
Treatment	121.272	1	121.272	105.187	.000	.691
Gender	.237	1	.237	.206	.652	.004
Treatment & Gender	6.369	1	6.369	5.524	.023	.105
Error	54.187	47	1.153			
Total	690342.200	52				
Corrected Total	31587.049	51				

Table 4.2.10 shows that there was no significant interaction effect of treatment by sex on swimming Endurance ($F_{(1,47)}=5.524, p<0.05, \eta^2=0.023$) of swimmers in Lead City International

School, Ibadan. The null hypothesis was therefore considered tenable. This implies that sex had no observable impact on swimming endurance of swimmers in Lead City International School.

Table 4.2.11: Estimated Marginal Means of Treatment and Sex on Swimming Endurance (Number of laps/time)

Treatment	Gender	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Experimental (dry-land training)	Male	110.554	.314	109.923	111.185
	Female	111.118	.303	110.509	111.727
Control (talk on benefits of exercise)	Male	114.693	.299	114.092	115.294
	Female	113.851	.324	113.199	114.503

Table 4.2.11 shows that male participants in the experimental group had a lower mean score (110.554) compared to their female (111.118) counterparts. The difference between males and females in experimental group in the estimated marginal means for swimming endurance is 0.564 with males having a lower value. In the control group, the male participants had a higher marginal mean score (114.693) than their female (113.851) counterpart. The difference between their marginal mean scores in swimming endurance is 0.842. This value is much higher than those for

the experimental group. The overall comparison shows that male participants in experimental group had the lowest mean score.

H₀₆: There will be no significant interaction effect of treatment and sex on swimming speed of swimmers in Lead City International School.

Table 4.2.12: ANCOVA Analysis of Interaction Effect of Treatments and Sex on Swimming

Speed of participants (Time)

Source	Type III Sum of			F	Sig.	Partial Squared	Eta
	Squares	df	Mean Square				
Corrected Model	1161.008 ^a	4	290.252	990.398	0.000	0.988	
Intercept	.312	1	0.312	1.065	0.307	0.022	
Pretest	1054.159	1	1054.159	3597.005	0.000	0.987	
Treatment	11.220	1	11.220	38.285	0.000	0.449	
Gender	1.014	1	1.014	3.459	0.069	0.069	
Treatment * Gender	0.043	1	0.043	.147	0.703	0.003	
Error	13.774	47	0.293				
Total	19905.005	52					
Corrected Total	1174.782	51					

Table 4.2.12 shows that there was no significant interaction effect of treatment and sex on swimming speed ($F_{(1,47)}=0.147$, $p<0.05$, $\eta^2=0.703$) of swimmers in Lead City International

School, Ibadan. The null hypothesis was therefore considered tenable. This implies that sex had no apparent impact on swimming speed of swimmers in Lead City International School.

Table 4.2.13: Estimated Marginal Means of Treatments and Sex on Swimming Speed of Participants (Time)

Treatment	Gender	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Experimental (dry-land training)	Male	18.619	0.153	18.312	18.926
	Female	18.398	0.150	18.096	18.700
Control (talk on benefits of exercise)	Male	19.618	0.152	19.313	19.924
	Female	19.280	0.150	18.978	19.582

Table 4.2.13 shows that male participants in the experimental group had a higher mean score (18.619) compared to their female (18.398) counterpart. The difference between males and females in experimental group in the estimated marginal means for swimming speed was 0.221 with males having a higher value. In the control group, the male participants had a higher marginal mean score (19.618) than their female (19.280) counterpart. The difference between their marginal

means in swimming endurance was 0.338. This value is much higher than those for the experimental group. The overall comparison shows that female participants in experimental group had the lowest mean score.

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4.3 Discussion of Findings

The result in this study revealed that there was a significant main effect of treatment on swimming endurance. This means that Dry-land Resistance training had effect on swimming endurance of swimmers in Lead City International School. This finding is in agreement with a previous study which determined the effect of Dry-land core training on physical fitness and swimming performance in adolescent elite swimmers¹. The result revealed that, anaerobic power, core stability, upper extremity muscular endurance, and swimming performance witnessed significant improvements as a result of the 12-week dry-land core training programme. In addition, after controlling for initial difference on swimming endurance, the participants exposed to dry-land resistance training had a lower mean score, while the control had a higher mean score. This implies that dry-land resistance training with the least mean score was more effective in relation to swimming endurance of Lead City International School Swimmers.

Furthermore, the result in this study further revealed that there was a significant main effect of treatment on swimming speed of swimmers in Lead City International School, Ibadan. This result is in line with a study conducted on, evaluation of energy expenditure in competitive swimming strokes². The result of the study revealed that, increased arm strength may lead to increased maximum force per stroke and as a result, increased swimming speeds, particularly in sprint length. The outcome of this study also corroborate a study conducted on the effects of dry-land strength training on competitive sprinter swimmers³. It was revealed that there was a significant improvement in sprint performance stroke frequency and stroke index. Additionally, another outcome of this study was that participants exposed to dry-land resistance training had a

lower mean score, while the control had a higher mean score. This implies that dry-land resistance training was effective in improving the swimming speed of swimmers in Lead City International School.

In regard to whether sex was a factor in training on swimming endurance, the result of this study revealed that there was no significant main effect of sex on swimming endurance of swimmers in Lead City International School, Ibadan. This implies that sex had no impact on swimming endurance. This result is in line with a study conducted on sex differences in youth elite swimming. The result revealed that there were no sex-related differences in swimming performance⁴. In another study on sex differences in elite swimming with advanced age, the result revealed that there was no gender difference in peak performance in ultra-endurance swimming performance⁵.

The result of this study indicated that there was no significant main treatment effect of sex on swimming speed of swimmers in Lead City International School, Ibadan⁶. The result of this study is in contrast to a study conducted on effect of dry land strength training on front-crawl swimming performance among undergraduate trainees. The outcome of the study revealed that there was a significant main effect of treatment and gender on swimming performance of swimmers (Strength, Speed and Endurance). The striking difference between the result of this study and the study was that the undergraduate trainees worked with weight training as treatment. Additionally, after controlling for initial difference of sex on swimming speed, female had a lower mean score than their male counterpart. This implies that dry-land resistance training had a better effect on female swimming speed.

Another finding of this study was that there was no significant interaction effect of treatment by sex on swimming Endurance of swimmers in Lead City International School, Ibadan. Male participants in the experimental group had a lower mean score compared to their female

counterparts. The difference between males and females in experimental group in the estimated marginal means for swimming endurance was lower for males. In the control group, male participants had a higher marginal mean score than their female counterpart. The overall comparison shows that male participants in experimental group had the lowest mean score. It implied that the interaction of treatment and sex had a better effect on male participants' swimming endurance who were exposed to dry-land resistance training than their female counterparts and the control group though the differences were not significant.

Finally, this study shown that there was no significant interaction effect of treatment by sex on swimming Speed of swimmers Lead City International School, Ibadan. Male participants in the experimental group had a higher mean score compared to their female counterpart. The difference between males and females in experimental group in the estimated marginal means for swimming speed was lower for females with males having a higher value. In the control group, the male participants had a higher marginal mean score than their female counterpart. The overall comparison shows that female participants in experimental group had the lowest mean score. It implied that the interaction of treatment and sex had a better effect on female participants' swimming speed who were exposed to dry-land resistance training than their male counterparts and the control group though the difference are marginal.

Endnotes

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2. A. Barbosa, THN. Ferreira, LV. Leis, V. Gourgoulis, & R. Barroso, *does a 4-week training period with hand paddles affect front-crawl swimming performance?* **J Sports Sci.** 2020;38(5):511–7.
3. J. Tiago Lopes, P. Henrique Neiva, A. Carlota Goncalves & Celia Nunes, *The Effects of Dry-land Strength Training on Competitive sprinters swimmers*. 2021, volume 19, 32-39.
4. W. Jonathan Senefeld, *Sex differences in youth elite swimming*, 14 (11), 2019, e0225724.
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Chapter Five

Conclusion

5.1 Summary of Findings

This study investigated the effect of 6-week dry-land resistance training on swimming endurance and speed of swimmers in Lead City International School, Ibadan. The study further accessed the resting heart rate of swimmers as well as determined the effects of a 6-week dry-land resistance training programme on swimming endurance; swimming speed as well as examined the effect of the treatment on swimming endurance; speed; sex and interaction of treatment with sex on endurance and speed. This were with a view to determining which of the training modes (6-week Dry-land resistance training) can better affect swimming endurance and swimming speed of swimmers in Lead City International School. Fifty-two (52) volunteer swimmers of the Lead City International School were purposively selected to take part in the study. They were pretested on the dependent variables and then matched and randomly assigned into experimental (26) and control (26). Descriptive statistics of frequency count, percentages, and bar charts were used to analyze the demographic data of the participants while inferential statistics of Analysis of Co-variance (ANCOVA) was used to test the hypotheses formulated at 0.05 level of significance. The findings of this study on socio-demographic characteristics revealed that, most of the participants were in the age range of 10-14 years.

This study also revealed that that there was a significant main effect of treatment on swimming endurance and speed of swimmers in Lead City International School. The estimated marginal means of treatment on swimming endurance and speed revealed that participants exposed to dry-land resistance training had a lower mean score, while the control had a higher mean score. More so, the findings of this study reveals that there was no significant main effect

of sex on swimming endurance and speed of Lead City International School swimmers, Ibadan. The estimated marginal means of sex on swimming endurance and speed of Lead City International School swimmers, Ibadan, revealed that female had a lower mean score than their male counterpart. Furthermore, findings of this study reveals that there was no significant interaction effect of treatment by sex on swimming endurance of Lead City International School swimmers, Ibadan. The estimated marginal means of sex reveals that males and females in experimental group in the estimated marginal means for swimming endurance is 0.564 with males having a lower value. In the control group, the male participants had a higher marginal mean score than their female counterpart.

Finally, the study recognized that there was no significant interaction effect of treatment by sex on swimming on Speed of Lead City International School swimmers.

5.2 Conclusion

Based on the findings of this study, it was concluded that dry-land resistance training was effective in enhancing swimming endurance and swimming speed of the participants. It was further concluded that sex was not a determinant of training outcome of swimming endurance and swimming speed of swimmers in Lead City International School, Ibadan.

5.3 Recommendations

The following recommendations were made:

Swimming instructor should be educated on the benefits of dry-land resistance training in order to improve swimming performance and that dry-land resistance training should be introduced to the swimmers as a means of improving swimming performance. Also, dry-land resistance training should be used by swimming instructor so as to reduce swimming injuries.

5.4 Contributions to Knowledge

This study has contributed to knowledge in the following ways:

1. This study confirmed that Dry-land resistance training is an effective training modality in improving the performance of swimmers in Lead City International School, Ibadan.
2. It was also confirmed that dry-land resistance training can certainly make the ab muscles burn and also develops a stronger core to give swimmers more control.
3. It was established that irrespective of sex, Dry-land resistance training can bring about training effect on swimming endurance and speed of the participants.

5.5 Suggested Areas of Further Research

The following recommendations were made for further research based on the findings of the study.

1. The study of this nature can be carried out among secondary school swimmers and adults with issues relating to swimming endurance and speed.
2. Duration, frequency and intensity of dry-land training that are applied in this study can be varied to determine their effects on swimming endurance and speed.