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Physiological and Psychological Aspects of Pacing Strategies in Half marathon

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стратегије темпа трчања у полумаратону

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Physiological and Psychological Aspects of Pacing Strategies in Half marathon

ABSTRACT

Purpose: The study evaluated how physiological and psychological motivating factors affect half-marathon performance, measured by race time and pacing strategy variability, in Lebanese recreational runners.

Methods: Cross-sectional study of 90 recreational Lebanese runners. Controlled field tests assessed speed, flexibility, cardiovascular, and muscular endurance. Pacing strategy variability was calculated using Garmin/Strava split-based GPS pacing data from 1 km race segments. Official race times for the 21.1 km race were recorded. Pearson's correlation, multiple linear regression, T-Tests, and ANOVA were used to determine gender differences and variable relationships.

Results: $VO_2\text{max}$ was significantly and negatively correlated with race time ($r = -.317$, $p = .004$), Speed showed the largest positive correlation ($r = .004$) with a meta-analytic approach ($r = .272$, $p = .013$). More stable pacing strategies were associated with sit-ups ($r = -.319$, $p = .004$), and this association was linear, suggesting a correlation between core muscle endurance and stability. Among both male and female recreational endurance runners, average pacing-strategy variability was $13.3 \pm 8.0\%$, indicating relatively inconsistent pacing profiles. The present study demonstrated moderate-to-large gender differences ($\eta^2 = .151-.354$) in sprint performance, muscle endurance, and race time. Psychological motivating factors had minimal and non-significant associations with race time and pacing strategy variability.

Conclusion: $VO_2\text{max}$, muscular endurance, and sprint performance were associated with half-marathon performance and pacing strategy variability in Lebanese recreational runners, whereas psychological factors showed limited predictive power. These findings emphasize endurance fitness, neuromuscular training, and pacing plan management in recreational half-marathon preparation.

Keywords: Endurance Running; Recreational Athletes; Cardiorespiratory Fitness; Exercise Motivation; Muscular Endurance; Race Strategy.

Scientific field: Physical education and sport

Scientific subfield: Physical Education, Sports and Recreation Sciences

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САЖЕТАК

Циљ: Ова студија је имала циљ да процени утицај физиолошких и психолошких мотивационих фактора на перформансе у полумаратону код либанских рекреативних тркача, процењене преко времена трке и варијабилности стратегије темпа трчања.

Метод: Сprovedена је трансферзална студија на узорку од 90 рекреативних тркача из Либана. Теренски тестови коришћени су за процену брзине, флексибилности, кардиоваскуларне издржљивости и мишићне издржљивости. Варијабилност стратегије темпа израчуната је коришћењем ГПС података о темпу заснованих на Гармин/Страва сегментима трке од 1 км. Званична времена за трку на 21,1 км су евидентирана. За утврђивање родних разлика и односа између варијабли коришћени су Пирсонова корелација, мултипла линеарна регресија, т-тестови и АНОВА.

Резултати: VO_{2max} је био значајно и негативно повезан са временом трке ($r = -0,317$, $p = 0,004$). Брзина је показала највећу позитивну корелацију ($r = 0,272$, $p = 0,013$) у оквиру мета-аналитичког приступа. Стабилније стратегије темпа биле су повезане са бројем трбушњака ($r = -0,319$, $p = 0,004$), при чему је ова повезаност била линеарна, што указује на однос између издржљивости мишића трупа и стабилности темпа. Код мушких и женских рекреативних тркача просечна варијабилност стратегије темпа износила је $13,3 \pm 8,0\%$, што указује на релативно неконзистентне профиле темпа. Ова студија је показала умерене до велике родне разлике ($\eta^2 = 0,151-0,354$) у способностима спринта, мишићној издржљивости и времену трке. Психолошки мотивациони фактори показали су ниске повезаности са временом трке и варијабилношћу стратегије темпа које нису достигле статистичку значајност.

Закључак: VO_{2max} , мишићна издржљивост и способност спринта били су повезани са успешношћу у полумаратону и варијабилношћу стратегије темпа код либанских рекреативних тркача, док су психолошки фактори показали ограничену предиктивну вредност. Ови налази наглашавају значај аеробне издржљивости, неуромишићног тренинга и управљања планом темпа у припреми рекреативних полумаратонаца.

Кључне речи: трчање на дуге стазе; рекреативни спортисти; кардиореспираторна издржљивост; мотивација за вежбањем; мишићна издржљивост; стратегија трке.

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ABBREVIATIONS

ANOVA – Univariate Analyses of Variance
MANOVA- Multivariate Analyses of Variance
L.O.C. – Levels of Confidence
MRA – Multiple Regression Analysis
KST- Kolmogorov-Smirnov test for distribution homogeneity
SD – Standard Deviation
Min – Minimum
Max – Maximum
cV% – The Coefficient of Variation
D: effect size
P: p-value.
SPSS – Statistical Package for the Social Sciences
GPS: Global Positioning System
BMI – Body Mass Index
FTP: Functional Threshold Power
IAAF: International Association of Athletics Federations
MPO: Mean Power Output
TSS: Training Stress Score
ACC: Anterior Cingulate Cortex
TDCS: Transcranial direct current stimulation
MF: Mental Fatigue
RPE: Rating Perception of Effort
V'O₂: oxygen uptake
RVEDD: Right Ventricular Diameter
RAvol: Right Atrial Volume
RVWT: Right Ventricular Wall Thickness
TAPSE: Tricuspid Annular Plane Systolic Excursion

BH – Body Height
BIA – Bioelectrical Impedance Analysis
ADH: Antidiuretic Hormone
THI: Temperature-humidity index
Vo²max: Maximum Volume of Oxygen
CFD: Computational Fluid Dynamics
ACS: Average Change in Speed
MAS: Maximal Aerobic Speed
MaaS: Maximal Aerobic Ascensional Speed
GLMM: Generalized Linear Mixed-Effects Model
RCTs: Randomized Controlled Trials
RPE: Rating of Perceived Exertion
SDT: Self-Determination Theory
EFA: Exploratory Factor Analysis
MOMS Motivation of Marathon Scale
AMRAP: As Many Repetitions as Possible
DV: Dependent variable
TR: Race Time

CHAPTER ONE: INTRODUCTION

Over the past several decades, endurance running has gained substantial recognition, leading to the popularity of marathons and half marathons. However, each distance requires a different approach and tactic; selecting the most appropriate pacing strategy based on energy system contributions is a crucial factor in determining athletes' performance during these events (Nikolaidis & Knechtle, 2018). Moreover, the regulation of pacing strategies affects sports performance, as it is an involuntary process involving multiple organ systems working in unison (Sha et al., 2024). In the middle of this regulation is the brain, which is the main controlling organ, regulating exercise and pacing strategy, providing continuous information through intricate afferent feedback and stimuli concerning the internal environment, to lead the runner in speed adjustment, energy use, and effort throughout the race (Nikolaidis et al., 2018). In addition to a number of factors that can influence how individuals cover the entire race distance and still achieve a result, pacing is especially vital, as energy resources are distributed during the run in a way that allows individuals to attain better outcomes. It is crucial for enhancing and perfecting performance, aiding race tactics and competition control, speeding physiological and psychological recovery, and minimizing the risk of injury (Hanley, 2016).

Furthermore, pacing strategies are a particularly important aspect in marathon and half-marathon running (Díaz et al., 2018). Maintaining a steady pace permits runners to achieve their optimal energy output without early exhaustion during the race (de Koning et al., 2011). This consistency in pace is a difficult and complex process; however, it not only helps an athlete perform well in the race but also helps minimize injuries and enhance the racing experience. Furthermore, an effectively implemented pacing strategy provides runners with a significant psychological benefit, in addition to the physiological advantage, as it enables them to maintain concentration, sustain motivation, and maintain morale throughout the activity (Fullerton et al., 2017). Pacing allows for a balanced cognitive and emotional state, enhancing performance under the burdensome requirements of endurance running. Understanding the mechanisms that enable runners to sustain paces can benefit not only athletes but also coaches and sport scientists interested in improving performance and reducing the risk of overexertion, exhaustion, and injury (Bargoria et al., 2020). Pacing research findings could therefore be used to design evidence-based recommendations regarding pacing styles for both athletes' training and competitions, which, in turn, refine performance and safeguard runners' psychological and physiological well-being (Nikolaidis et al., 2018). Such knowledge can be valuable to athletes, helping them reach their maximum physical capacities and achieve goals in endurance-based events (Breen et al., 2018).

Marathons are endurance running events over a distance of 42.195 km. Historically, they first got introduced at the inaugural Modern Olympic Games in 1896 (Sabina et al., 2018). Since then, marathons have been included in every subsequent Olympic Games, and nowadays they symbolize the ultimate running challenge for athletes. Even though a full marathon is the classical endurance running event, the race of half that distance, 21.1 km, known as the half-marathon, has become an attractive alternative for lower-level and recreational runners. These shorter distances are an accessible entry point into this type of

endurance sport while maintaining pace, energy distribution, and various strategies. Furthermore, the widespread popularity of both marathons and half marathons is stimulating a range of societal phenomena that have been provoked by these endurance events, thereby enhancing their appeal over time (Marc et al., 2014). An example of such a well-known iconic event is the "Marathon des Sables", also referred to as the toughest footrace on Earth, a six-day ultramarathon in the Sahara Desert, conducted as well as a fund-raising occasion by sport-related non-governmental organizations (Marc et al., 2014). On the other hand, the analogy of significant world events with Olympic medal achievements has brought into the world great propagative properties for both the marathon and half-marathon, in addition to the cultural and symbolic associations, creating a global interest in the physiological and psychological aspects of long-distance running (Marc et al., 2014).

Moreover, over the several years between 1985 and 2011, 1,490 finishers from twenty-four European countries, along with the United States of America, participated in the Double Iron ultra triathlons, underscoring the global appeal of multi-discipline endurance competitions (Sigg et al., 2012). Additionally, in the early 20th century, marathons developed into mass-participation events in cities around the world. Moreover, organized by the Boston Athletic Association in 1897, the Boston Marathon became popular and is considered the longest-running annual marathon in the world. Huge popularity growth in marathons occurred during the current era, as hundreds of races take place annually across multiple international locations (Sabina et al., 2018). The World Marathon Major competitions, consisting of New York City Marathon, London Marathon, Berlin Marathon, Chicago Marathon and Tokyo Marathon, attract both tens of thousands of participants and millions of spectators to each event every year, highlighting the extensive societal attention on endurance running and the gradually polished demands set upon athletes to enhance performance through careful planning, pacing, and training strategies (Sabina et al., 2018).

The consistent interrelationship between exercise intensity and physiological as well as psychological responses is a crucial factor that ensures a somewhat stable homeostasis during the lengthy intense activities (Travers et al., 2022), and minimizing the risk or even preventing the development of severe hyperventilation (González-Alonso et al., 2023), cardiac drift, hyperthermia, and dehydration with exercise-induced hypoglycemia and hyponatremia (Montain & Coyle, 1992).

Therefore, the goals of this study were to present the basic knowledge of pacing strategies, specifically in half marathons, to determine the most influential factors, and to examine the physiological and psychological factors that influence the pacing strategies adopted in a half marathon to sustain optimal performance throughout. By providing a comprehensive understanding of even pacing and its influencing factors, a scientific contribution to endurance performance can be made, along with practical guidance for athletes, coaches, and amateur runners to improve their performance in training and competition.

CHAPTER TWO: LITERATURE REVIEW

2.1 Historical Overview of Pacing Strategies

An athlete's endurance performance in a marathon or half-marathon relies on their ability to regulate effort and choose an effective pacing strategy. Pacing depends on several physiological and psychological factors and has evolved alongside marathon competitions. The transformation of marathons, from the legend of Pheidippides to the modern Olympic Games, fostered the development of proper pacing strategies to achieve optimal results in training and competition. Thus, a historical overview helps explain how today's models have formed.

2.1.1 *The History of Marathons*

The debatable legend of the name comes from Pheidippides, a Greek messenger. He supposedly ran from Marathon to Athens to announce their victory, then lost consciousness and died (Sabina et al., 2018). When the Olympic Games began at the end of the 19th century, the founders wanted to honor Greece's glory. Michel Bréal, supported by Pierre de Coubertin, suggested a marathon race to honor the legend. After this decision, the Greeks organized a selection marathon, which was won by Charilaos Vasilakos in about 3 h 18 min.

2.1.2 *The History of the Distance*

Another important aspect in the evolution of marathons and half marathons is the distance, which was not set in the first few Olympic Games, because the focus was on making the competitors run the same course; however, it was approximately 40 kilometers, the precise distance between the Plain of Marathon and Athens' Panathinaikos Stadium (Sabina et al., 2018). Nonetheless, the distance varied continuously depending on the location of the Olympic Games, making it difficult to establish a consistent base for analyzing performances and setting a proper pacing strategy (Sabina et al., 2018). It remained an instinctive decision for each course rather than a scientific strategy. However, after the British Olympic Association agreed with the International Olympic Committee to include a 40-kilometer marathon in the 1908 Olympic Games, several route changes were made (Krentz, 2010). The final distance was 42.195 kilometers, and the Italian runner Dorando Pietri crossed the finish line in the stadium center first but was disqualified for receiving assistance in his final 195 meters, when he kept falling, creating a critical fatigue zone, or what is known nowadays as "end-spurt failure". Queen Alexandra, being moved by Pietri's effort and resilience, rewarded him with a silver-gilt cup the following day, even though it was Johnny Hayes who won the gold medal, creating a historical moment to be remembered (Krentz, 2010).

This marathon race flared its popularity worldwide, causing a "marathon fever", thus several races and associations took on the same distance of 42.195 kilometers, such as the

Polytechnic Marathon, The International Amateur Athletic Federation in 1921, and finally it was officially set in the 1924 Olympic Games, after it was varying from 40 to 42.195 km across the past seven Olympic Games (Sabina et al., 2018).

Alongside the evolution of its distance, marathons and half marathons' pacing strategies evolved from being made on instinct to being informed by scientific research and educated decisions based on proven strategies. Since the 1984 Olympic Games, when the women's marathon was introduced (Sabina et al., 2018). The scientific literature has described various pacing strategies used by athletes in major marathon competitions, and a wealth of evidence has highlighted their effects on overall race outcomes.

2.1.3 The History of Pacing Strategies

Pacing strategy has been operationally defined as the pattern of running speed over race segments within a half-marathon event (Krentz, 2010). Split pace was determined as the average for each 5 km interval (i.e. 5, 10, 15 and 20 km + final 21.1km split).

Before the 1990s, the most common way for top marathon runners to set their pace was the positive split strategy, which involves going out fast at the beginning and gradually slowing down as the race progresses (Krentz, 2010). These days, runners often use even or negative splits, which means they either keep their pace pretty steady or run the second half of the race faster than the first (Krentz, 2010). While recreational runners tend to exhibit positive pacing patterns with gradual deceleration in the final stages of the race, elite runners are generally capable of maintaining a relatively stable pace or running slightly faster in the final 5 km of the race due to their superior physiological condition, fatigue resistance, and pacing regulation abilities (Haney & Mercer, 2011; Nikolaidis et al., 2019; Ristanović et al., 2023). From the 1920s to the 1950s, pacing usually involved starting quickly and then gradually slowing down after about 25 km. This was because scientists didn't know much about how to distribute energy and control endurance pacing at that time (Krentz, 2010). During this time, athletes relied more on their own subjective pacing techniques than on scientifically based models (Krentz, 2010). Interval training with up to 600-meter repeats and weekly training volumes reaching approximately 160 km/week were the main forms of exercise used during this time (Tjelta & Enoksen, 2001).

Moving on to the time between the 1960s and the 1980s, when interval training was used more and more, accelerating the athlete's heart rate to 180 bpm with recoveries. Frank Shorter was one of the elite athletes who used this method of training for sparing speed. Nevertheless, even with the high reliance on positive pacing, pacing began to appear more optimal in various studies (Tjelta & Enoksen, 2001). In the aftermath of the analysis of 15 men's world records between 1967 and 2014, it shows a clear change in pacing strategy that started focusing on negative or even pacing, between the 1990s and 2000s, where Sub-threshold tempo runs were used to maintain endurance for longer times, at a faster pace (Diaz et al., 2018; Sha et al., 2024). However, since the 2010s, the popular pacing strategy used by elites and runners, supported by numerous reviews, has been even pacing, with speed spurts at the end of the competition. In addition, wearables and GPS tracking are now available to aid in pacing adjustments during the run (Sha et al., 2024).

Beginning from the historical Pheidippides' run to the first Olympic Games marathon, and the unorganized pacing strategies used by athletes, marathon and half-marathon runs have evolved greatly. Many marathon races held over the 20th century were successful in creating legends and popularizing the event, delivering awe-inspiring world-record performances and historic moments.

The marathon is regarded as the foremost event of athletic endurance and has never ceased to fascinate both runners and fans, since it represents the ultimate test of human abilities. This discipline is considered so demanding not only because it affects multiple physiological systems, particularly the metabolic, cardiovascular, thermoregulatory, and musculoskeletal systems, but also because it requires significant coordination between the human body's biological systems and non-physiological factors, including race tactics, environmental conditions, personal motivation, and individual experience.

2.2 Pacing Strategies in Different Phases of a Race

The literature review of research on the pacing strategies of various branches of athletic events revealed particular concern about endurance-event pacing. Renfree and Gibson (2013) provided essential insights into how different performance standards influence pacing strategies in marathon events. The documentation of the IAAF Women's Marathon Championship of 2009 revealed that pacing strategies are differential. The elite athletes are classified according to their respective performance levels, with Groups 1-4 maintaining speeds of $98.5\% \pm 1.8\%$, $97.4\% \pm 3.2\%$, $95.0\% \pm 3.1\%$, and $92.4\% \pm 4.4\%$, respectively. The fastest group maintained low speeds during the early parts of the race and high speeds during the latter parts. Unsustainable speeds by other groups resulted in poor performances below their PBs due to major-event psychology. This has revealed that pacing strategies have to be deliberate, while champions are capable of controlling their energy reserves according to internal and external demands, which is a recurring theme of all endurance literature (Renfree & Gibson, 2013). Wu et al. (2014) analyzed pacing strategies in triathlons, races comprising sequential swimming, cycling, and running sections. The authors found that athletes had to control their energy expenditure not only over the entire race but also within each segment, given the interdependence among race segments. In endurance events such as the Ironman triathlon, insufficiently paced cycling can impair later running performance, whereas cycling at an appropriate intensity can help conserve energy for subsequent segments. These findings support the notion that pacing is a complex, dynamic process that requires athletes to employ controlled, sport-specific pacing strategies during competition (Wu et al., 2014).

Similarly, Davies et al. (2016) used meta-analytic approaches to explore the links between pacing strategies, environmental influences and performance feedback. Their results indicated that pacing behavior is affected by a number of complex variables, including hypoxia, thermal stress, job duration, experience, motivational states and feedback from external sources. Environmental challenges such as hypoxia and heat were shown to reduce power output during endurance performance, while effective feedback methods could be used to improve pacing regulation. The authors found that pacing strategy is not fixed and is constantly adapted during competition, depending on physiological, psychological, and

environmental factors. These findings indicate that control of pacing strategy is complex, and it is important to acquire the right amount of energy at each stage of an endurance event.

Studies on pacing in endurance running show that elite and high-level runners mostly exhibit a relatively even strategy with low pacing variability values (2–5%) while recreational and lower-level runners often present higher values of pacing variability (larger than 6–10%), even reaching very high percentage (10 or more %) due to incapability to maintain pace during the last phase of the race induced by greater fatigue, signaling performance decline (Haney & Mercer, 2011; Ristanović et al., 2023).

Overall, these articles provide further insight into the different stages of endurance racing by addressing distinct thought processes about the most effective means of energy expenditure to enhance race outcomes, as inferred from the focus on even splits and TSS (Training Stress Score) in multisport racing events. The knowledge gained from reading these articles further reinforces the importance of pacing across various forms of competitive endurance racing, providing a basis for further exploration of this vital aspect of competitive athletics.

2.3 Psychological Determinants of Half-Marathon Performance

It has been shown that cognitive factors play an important role in pacing strategies used during self-paced endurance competitions (Brick et al., 2015). This effect of cognitive factors on pacing strategies highlights the importance of understanding the psychological aspects of endurance sport and the management of perceptions of effort during endurance events. The relevance of the multidisciplinary approach to endurance physiology in endurance events has recently been revealed. The reciprocal interaction between the brain and exercise dyspnea positions cognitive processes as one of the most relevant factors in understanding exercise performance (Stillman et al., 2020). Athletes' expectations must be taken into account to understand the factors influencing the implementation of pacing strategies. The physical capabilities of the endurance athlete should be considered a multidimensional interaction among psychological, physiological, technical, and tactical characteristics. Endurance events require a complex interplay of psychological, physiological, tactical, and environmental factors that influence the pacing strategy adopted by individuals, athletes, or teams. It has been observed that self-paced pacing strategies are typically used in endurance events. To maintain a constant speed during a marathon, the athlete must monitor the intensity of their self-selected pace and perceive sensory information about potential changes in speed.

Current research on the regulation of self-paced exercise in endurance events, such as cycling and running, shows that this exercise is predominantly determined by physiological limitations, such as muscle fatigue (Schiphof-Godart & Hettinga, 2017). In contrast, it has also been observed that the pattern of self-selected pacing itself may be classified as a complex behavior that depends on physiological restrictions and deliberate decisions. During sustained exercise, information from various physiological systems, such as the reflex control system, becomes increasingly important in effectively adjusting exercise

intensity to maximize exercise performance. The control system processes information from various physiological systems and influences the body's motivational state, an important guide for exercise behavior. This monitoring function has a salience system enabling the motivated body to focus attention on its ongoing physiological state, and in accordance with the information derived from the salience system, the flow of information from the different physiological systems supports the ability to flexibly adjust exercise intensity for optimal self-endurance performance (Sakalidis et al., 2021). Despite some dissociation, these ideas together point to psychological determinants in the pacing strategies during self-paced endurance, physical, and mental efforts, temporarily derived from goal definition.

2.3.1 Motivation in Endurance Running

Motivation is one of the most important psychological determinants of endurance sport participation and performance. It refers to the internal and external processes that initiate, direct, and sustain goal-oriented behavior. In sport settings, motivation influences an athlete's willingness to train, persist through physical discomfort, overcome challenges, and strive toward personal or competitive goals. Endurance running, in particular, requires sustained commitment over extended periods of training and competition, making motivation a fundamental factor in both participation and performance outcomes. Athletes with higher levels of motivation are generally more likely to adhere to training programs, maintain long-term engagement in sport, and effectively cope with the physical and psychological demands associated with endurance events (Alkawasbeh & Akroush, 2025; Junfeng, 2025).

Contemporary motivational theories suggest that motivation exists along a continuum ranging from intrinsic to extrinsic forms. Intrinsic motivation refers to engaging in an activity for the inherent satisfaction, enjoyment, challenge, or sense of accomplishment it provides. In contrast, extrinsic motivation involves participation driven by external rewards, social recognition, competition, status, or other outcomes separate from the activity itself. According to Self-Determination Theory, intrinsically motivated athletes often demonstrate greater persistence, psychological well-being, and long-term sport commitment than those motivated primarily by external rewards. However, both intrinsic and extrinsic motives can simultaneously influence endurance athletes, shaping their training behaviors, competition strategies, and performance outcomes (Deci & Ryan, 2000; Alkawasbeh & Akroush, 2025).

In endurance sports such as half-marathon running, motivation plays a particularly important role because athletes must repeatedly regulate effort, tolerate discomfort, and maintain performance over prolonged durations. Motivated runners are generally more likely to sustain demanding training schedules, adhere to nutritional and recovery practices, and persist during periods of fatigue encountered during competition. Motivation also contributes to the development of self-regulation skills that enable runners to make effective decisions before and during races. Consequently, motivation is often considered a key psychological resource supporting endurance performance and successful completion of long-distance events (Gardner et al., 2017; Marheni et al., 2019).

One of the most widely used frameworks for examining motivation among distance runners is the Motivations of Marathoners Scale (MOMS), originally developed by Masters et al. (1993). The MOMS identifies multiple dimensions of running motivation, including health orientation, weight concern, personal goal achievement, competition, recognition, affiliation, psychological coping, self-esteem, and life meaning. These motivational domains reflect the multifaceted reasons individuals participate in endurance running. Research has shown that runners are rarely motivated by a single factor; rather, participation and performance are influenced by a combination of health-related, achievement-oriented, social, and psychological motives that may vary according to age, gender, experience, and competitive level (Masters et al., 1993; Nikolaidis & Knechtle, 2018).

Motivation may also influence pacing behavior during endurance events. Pacing strategy refers to the distribution of effort throughout a race and is considered one of the most important determinants of endurance performance. Motivated athletes may demonstrate greater willingness to tolerate discomfort, maintain target race intensity, and adjust effort levels in response to changing physiological and environmental conditions. Psychological motives such as personal goal achievement, competition, self-esteem, and psychological coping may therefore contribute to the selection and maintenance of pacing strategies during half-marathon performance. Because pacing decisions are continuously regulated throughout the race, motivation may serve as an important psychological mechanism influencing how athletes allocate their physical resources over time (Brick et al., 2015; Schiphof-Godart & Hettinga, 2017).

Despite the theoretical importance of motivation, empirical findings regarding its relationship with pacing and endurance performance remain mixed. Several studies have reported positive associations between motivational factors, training adherence, race participation, and athletic achievement (Gardner et al., 2017; Marheni et al., 2019). However, Nikolaidis and Knechtle (2018) found no significant association between motivational dimensions and pacing characteristics among recreational marathon runners, suggesting that pacing behavior may be influenced more strongly by physiological capacity, experience, and tactical decision-making than by motivational factors alone. These inconsistent findings highlight the need for further research examining how different motivational dimensions relate to pacing variability and race performance among recreational half-marathon runners.

Recreational runners have complex psychological profiles that may affect training and performance. Health, achieving personal goals, competition, self-esteem and mental health are among the most salient reasons for running marathons and half-marathons. These motivational factors may be relevant to differences in pacing and race success; thus, they are important psychological factors to study in endurance sports.

2.3.2 Goal Setting and Achievement Processes

Goal-setting research within sport has examined the motivational effect of various goal-setting conditions. It was found, in an early meta-analysis of this area, that generally positive effects of all types of assigned goals, which were defined as specific difficult goals, 'do your

best' goals (without reference to specific levels), and no goals. Both specific and brief feedback on progress and learning goals resulted in higher levels of achievement than 'do your best' goals (in all criterion domains, including task performance, learning, and overall job performance). In every criterion test, both goal conditions produced higher levels of productivity than the no-goal condition. Task type moderated the effects of these goal conditions, with feedback and learning conditions leading to greater effects for tasks requiring physical (vs. intellectual) activity. Similar, larger effects of difficult goals occurred over no goals only when these were used as training agreements and implemented through situational goal mechanisms (i.e., promoting goal commitment and plans for achieving them), pre-training discussion, or a combination of training agreements with situational goal mechanisms. Based on the meta-analysis, goal setting appeared to be a pervasive technique for improving task performance across a broad range of tasks (Sakalidis & al., 2021). In addition, several researchers considered motivation a psychological factor that significantly influences pacing. On the other hand, Nikolaidis (2018) found no correlation between pacing and motivations (Nikolaidis & Knechtle, 2018).

In endurance running, goal setting may influence pacing behavior by providing runners with specific performance targets, such as finishing times, split times, or pacing zones. Athletes frequently use process, performance, and outcome goals to regulate effort distribution throughout a race and maintain adherence to pacing plans.

Therefore, the athlete would set a target to reach a certain time at the end of the race, a certain speed, or a certain position relative to other athletes (Wu et al., 2014). Once it is set as a target, the pacing strategy can help the athlete achieve it through swimming, cycling, and running. For example, the athlete can compare his or her goals with the race's process to determine whether he or she needs to increase or decrease speed.

However, problems are bound to occur, especially when the goals the athlete has set exceed their physical capacity (Fullerton et al., 2017). In this case, the athlete's eagerness to attain a goal beyond their physical capacity might prompt them to start the race at a pace they cannot sustain. This might prompt the athlete to report a higher perceived exertion, which could affect their performance in later segments as they are forced to slow down due to fatigue, potentially leading to a performance collapse.

2.3.3 Mental Fatigue and Decision Making

Mental Fatigue (MF) has become apparent in the past few years as a factor that negatively impacts sport-specific performance, yet it differs from "physical fatigue". It is defined as a psychobiological state resulting from prolonged, demanding mental activity. The state of mental fatigue is characterized by increased perception of effort and unpleasantness during different types of physical activity and by lower performance during physical demands that require cognitive control of movement. Apart from motor skills, other researchers, such as Fortes et al. (2019) and Gantois et al. (2020), have argued that another obvious sensitive perceptual-cognitive capacity related to the football game (e.g., decision-making) is significantly affected in MF. More particularly, perceptual-cognitive skill might be defined as the ability to seek out signal cues appropriately and use them in conjunction with existing

information to react appropriately. Therefore, any compromise with the noble perceptual-cognitive skill could be costly in terms of game performance or loss. The decision-making process for cognitive effort involves the desire and willingness to exert the required cognitive effort to achieve certain gains or rewards, and this is a function of three variables: importance, effort, and the expected validity of the reward. This concept includes aspects related to cognitive abilities, which define the type of decision required, the level of noise in the decision-making process, and the expected reward-consequence associated with the task. Mental fatigue significantly increases heart rate, and this effect was moderated by age, with older players showing greater declines in performance (Filipas et al., 2021). On the other hand, mental fatigue can make someone's self-efficacy and exercise enjoyment more sensitive to the time of day. For instance, Hess & Knight (2021) revealed that chronic mental fatigue had varying degrees of predictability as concerns of expected engagement and assessment in various groups (Hess & Knight, 2021). However, it is important to note that MF alters the rating perception of effort (RPE) established in the psychological theory of exercise. This implies that MF modulates adenosine levels by engaging the anterior cingulate cortex (ACC) while simultaneously reducing dopamine levels. This proposition has been confirmed in an experiment concerning sport-specific performance. On the other hand, transcranial direct current stimulation (tDCS) can interfere with the enhancement of RPE during exercise tasks. Consequently, tDCS has achieved academic interest as a technique to minimize MF effects and enhance performance in the sports context (Sun et al., 2024).

2.3.4 Cognitive Strategies and Self-Regulation

Cognitive skills help athletes to maintain their speed during extended competitions. Athletes benefit from using goal-setting self-talk techniques and mental imagery, along with focused attention control methods, to manage their race energy and maintain their running speed. They are required to constantly assess their current performance and decide on their running speed, which involves mental processes that enable them to monitor progress and maintain their targeted objectives while adapting their racing strategies to race developments (Fullerton et al., 2017)

Athletes who use goal setting as their mental strategy monitor their running speed during this process; however, athletes who establish race objectives prior to competition use those objectives to maintain their desired running speed (Fullerton et al., 2017). Therefore, to fulfill their objectives through specific training activities rather than reacting to current fatigue and environmental conditions, athletes use their goals to regulate their effort levels.

During the race, athletes can use self-talk by repeating phrases such as "keep a rhythm" or "save some energy" to maintain their pace and running speed while determining their necessary effort level. The system enables athletes to use reminders, which help them maintain their desired speed without unintentionally exceeding their planned pace.

In addition, they use external factors to determine their running speed, including their current pace, feedback from course markers, and observations of other competitors.

Athletes then use these elements to assess their running speed and pace, which they need to maintain to achieve their desired performance level and reach their targeted goal.

Athletes who run Marathons develop greater mental strength simply from the training they do. This is caused by differences in concentration and self-discipline across swimming, running, and cycling (Wu et al., 2014). Starting with swimming, athletes first have to maintain their rhythm, enabling them to maintain their pacing speed, followed by the concentration on their cycling rhythm, which enables them to maintain their speed at a constant level, and finally, athletes have to use their stride length and rhythm while running, to maintain their speed while handling their fatigue (Wu et al., 2014). The mental strategies enable athletes to maintain pacing stability across all race segments.

Cognitive strategies serve as tracking tools, enabling athletes to maintain concentration while managing their physical output throughout the triathlon (Foster et al., 2009). The tracking system enables athletes to maintain their pacing at set intervals while attaining their pacing goals.

2.3.5 Exercise Duration Knowledge, Expectations, and Prior Experience

Experience from the past, together with knowledge of how long the workout will take and its difficulty, is quite important for psychological pacing control in endurance sports and for determining how to divide the athlete's efforts (Foster et al., 2009). Moreover, past experiences are an essential factor in understanding how the body reacts to long-duration workouts, such as swimming, cycling, and triathlon disciplines.

The expectations of triathletes can be adjusted over time regarding effort, time, and fatigue progression by continually exposing them to race distances, conditions, and settings (Wu et al., 2014). Eventually, they can develop the ability to foresee the difficulties they may face in certain parts of the race and the effort required for different parts (Wu et al., 2014). They can thus adjust their self-selected pacing strategy from one race to another based on the knowledge they have acquired. Instead of relying on the "trial and error" method, triathletes can improve their ability to plan their pace to support better performance.

In most cases, the athlete would have a better chance of channeling their efforts in a balanced way if they have ideas about the race duration or race segments. This would mean they could maintain a constant speed throughout the race or save energy in the initial segments to maintain a certain speed later (Foster et al., 2009). In some cases, the athlete may have ideas about the effort to be put into certain segments based on their perceptions.

However, the effectiveness of pace decisions may be less successful when they are based on erroneous expectations. For example, the athlete may start at a pace that is too strenuous to sustain for the entire race when they underestimate the total race distance, the degree of challenge of the race terrain, and other environmental factors such as heat and wind. Such errors in decision-making may result in a pace decision that is too fast relative to the athlete's capabilities or in failing to distribute the pace adequately throughout the race. The athlete may not be able to perform in the later stages of the race when he/she gets too tired too

early. Pace decisions and performance in a race, such as a triathlon, are greatly influenced by a combination of experience, expectations, and knowledge of the race's duration.

2.3.6 Mental Toughness and Fatigue Tolerance

The concept of mental toughness, as it relates to athletes, may be described as the consistency of focus, effort, and pacing, both physically and mentally. Therefore, it assumes critical importance in long, arduous races such as Ironman races, where athletes must sustain physical and mental effort for longer periods as race duration increases (Krentz, 2010).

Furthermore, mentally tough athletes are expected to cope well with the gradual increase in physical discomfort as they progress in the race, whereas less mentally tough athletes are affected by fatigue and discomfort, leading to a sudden change in pace. Moreover, athletes are expected to maintain their focus, especially when they are in a physical state that suggests they are already fatigued and when the race is becoming more demanding. Additionally, athletes considered mentally tough are not expected to be affected by short-term factors that might cause them to suddenly change pace during the race. However, it is important to note that maintaining pacing integrity enables the individual to withstand the temptation to act impulsively during the race. A case in which an individual can show this is when they are aware that others are picking up the pace in the race. The individual with better mental control is in a position to decide whether his or her reaction to this is part of his or her pacing strategy. In this case, the individual can avoid burning out in the race.

On the other hand, the external factors, which in this case may comprise the expectations of sponsors, coaches, and even the social setting, may influence an athlete's pacing strategy differently. If an athlete was feeling under pressure, whether it was to deliver or to perform to a certain expectation, he or she may end up feeling like they have to use aggressive pacing strategies that are not in parallel with his or her optimal performance strategy (Foster et al., 2009), meaning that the athlete may end up starting the race at a high intensity, which will not be sustainable at a certain point, leading eventually to fatigue, thereby affecting his performance at a later part during the race. Mental toughness and the ability to combat fatigue are, therefore, very important in pacing strategies in long-distance triathlons (Wu et al., 2014).

2.3.7 Self-efficacy and Confidence

The role of the athletes' beliefs in their capabilities is crucial in understanding how they regulate their efforts in endurance races. This can be understood in reference to self-efficacy and self-confidence, which are defined as "the level at which the athlete is confident that they possess the capability to complete the task at hand and sustain this level throughout the endurance race." This psychological factor in pacing strategy is of great importance in determining the level of aggression the athlete can maintain at the onset of the endurance race and sustain as fatigue builds (Foster et al., 2009). By being confident in one's ability to handle challenges in the endurance race, the athlete is likely to adhere to a pacing strategy

that aligns with his or her performance rather than to impulses during the initial stages of the race.

High levels of self-efficacy can also ensure that pacing is stable and controlled. This is because an athlete with high levels of self-efficacy in his or her own training and in the ability to push to the end of the race can ensure pacing that aligns with one's race goals. This would ensure that the athlete does not start too fast and slow down too early in the race; instead, he would be able to pace himself, saving his energy and pushing to the end. This high level of self-efficacy would also help the athlete stay focused as fatigue builds.

2.3.8 Perception of Effort and Pacing

The psychological factors that determine an athlete's pace in endurance sports include the perceived exertion during training. This is defined as the rating of perceived exertion and is classified as a psychological determinant, since it reflects the feeling that the activity an athlete is doing at any given time is difficult (Zach et al., 2017). This plays a critical role in determining the pace at which an athlete runs during a race, since, rather than relying on the athlete's physical prowess, the brain constantly analyzes internal cues from the body. These cues are usually a combination of expectations formed over time regarding the race, the athlete, and the race itself.

Normally, in an endurance race, an athlete uses a pace strategy, starting with a conservative initial pace. In the initial stages, it is often perceived that an athlete is using less effort than in the latter stages. This helps control and minimize the energy the athlete uses (Marcora et al., 2009). However, as the athlete progresses in the endurance race, they can receive feedback on their condition and the distance remaining. Therefore, as the athlete progresses in an endurance race, he or she aims to increase the pace of exertion. Therefore, an athlete competing in an endurance race aims to maintain a constant pace or a negative split, increasing effort in the latter stages compared to the initial stages (Marcora et al., 2009).

In the case of pace regulation in a race such as a triathlon, it becomes even more complicated owing to the different parts of the race. For example, there is a part of the race in which the individual would be expected to participate in swimming, cycling, and running. There is also the component in which the individual would be expected to change from one component of the race to the next. The individual would also be expected to note the component in the race that would affect their pace. For example, the individual would have to prepare to run after a tough cycle in the race (Zach et al., 2017). However, when the perception of effort is not aligned with the demands of the race, pacing errors are likely to occur. For instance, an athlete may not perceive the effort required for the race; therefore, an athlete may end up running too fast and getting fatigued too early, or even running too slow due to the perception of too much difficulty in the next stages of the race. Therefore, the intricate relationship among perception, expectations, and feedback is crucial to pacing strategy in triathlon races (Zach et al., 2017).

2.4 Physiological Factors Influencing Pacing Strategies

The marathon is a unique and physically demanding event of a specific nature. A factor that makes this event special is the requirement for athletes to carefully plan and execute pacing strategies to achieve goals and compete at the best possible time. In the marathon, most athletes judge their performance by overall time. An optimal pacing strategy is imperative for achieving the best possible timing. However, a significant proportion of athletes start with the goal of just finishing the race. Nevertheless, they must also plan and execute their pacing strategy to fulfill this more modest goal (Ristanović et al., 2023).

The belief that a negative pacing profile (running speed that gradually increases from the start to the finish) is more efficient than a positive pacing profile, as the latter can negatively affect marathon finishing time, is firmly established. Because of this, optimal pacing profiling has been the main interest of sports scientists over the past 20 years. However, physiological and psychological factors that may influence pacing strategies in marathon and half-marathon races remain under investigation (Ristanović et al., 2023). In addition, the positive effect of high motivation has been identified in some sports, while negative psychological factors can predispose it to negative effects, such as a decrease in proper pacing. It is well known that physical performance declines exponentially in the final fractions of the race. These consequences are associated with various athletic injuries, including hospitalization. Due to a possible budget deficit in a sport, there is also a risk of life-threatening physical complications. The importance of studying the costs of quality pacing of the entire marathon and exploiting them to compete is crucial.

2.4.1 Gender

There was a disparity in pace between men and women, with men maintaining a relatively even pace throughout the marathon or long-distance race, while women maintained a more even pace. This is because women's pace decreased less; therefore, they maintained a relatively constant pace compared to men. Thus, it can be inferred that the pace of women was balanced from the beginning of the race to the end of the race.

It was also indicated in the research that the pace of women was relatively balanced in comparison to the pace of men in different marathons, such as the New York City Marathon (Nikolaidis et al., 2017), Olympic Games, IAAF World Championships (Hanley, 2016), and 14 marathons in the United States (Deaner et al., 2015). This indicated that women had not increased their pace at the beginning of the race, which would have reduced it later in the race. The men's pace varied: they raced aggressively at the start, then slowed in the latter stages.

These changes in pacing have been explained by various factors, including decisions, motivation, and physiological factors. A study on motives among male and female athletes found that women scored higher on motivational factors, including psychological coping, self-esteem, life meaning, health orientation, weight concern, and goal achievement. The same levels of motives, such as affiliation, recognition, and competition, have been observed in both male and female athletes. This shows that women have a high level of motivation

while participating in endurance races. It may also help women maintain a disciplined pace as they run the race. Physiological factors can be responsible for changes in pacing during running among male and female athletes. It has been observed that men are at high risk of rapid glycogen depletion in the initial stages of exercise, especially during racing with a fast initial pace (Sandbakk et al., 2018; Cuk et al., 2019). This may result in fatigue in the latter stages of the race, leading to a reduced pace. Women, on the other hand, have been shown to rely more on fat metabolism and to exhibit greater fatigue resistance during extended endurance exercise, which may lead to more consistent pacing during long-distance races.

2.4.2 Energy Systems and Metabolism

Pacing strategy has been recognized as an emerging issue in sports performance, with the physiological limits of human endurance increasingly evident. Therefore, extensive research has been conducted on energy distribution during a race. Various studies have examined the impact of energy consumption patterns on sports performance. Emphasis has been placed on races, in which the athlete is challenged to use limited energy. The energy flow model has been recognized as a tool for analyzing energy consumption during a race, and it has been used to forecast energy output based on various parameters during sports performance. The tool was effective in analyzing the athlete's energy consumption during a race and in identifying different patterns of sports performance related to aerobic and anaerobic energy production (Hettinga et al., 2007).

The amount of energy produced during exercise varies with its intensity and duration. For example, during supramaximal exercise lasting approximately 2 minutes, half of the total energy is produced anaerobically, while the other half is produced aerobically. For instance, studies examining 4000-meter cycling time-trial performance found no correlation between total aerobic work output across various pacing strategies and pacing strategy (Hettinga et al., 2007). Pacing strategy may affect the physiological responses underlying the dynamics of oxygen uptake during exercise, as observed in 500-meter kayaking. Pacing strategy may affect energy conservation during exercise, especially during long-distance running, such as negative split pacing, which may affect energy conservation during the initial stages. Pacing strategy may affect the production of the " $\dot{V}O_2$ slow component," which may vary with exercise intensity, especially in the later phases of endurance exercise, when athletes rely more on fat metabolism to produce energy as glycogen availability decreases (Hettinga et al., 2007).

2.4.3 Cardiovascular Responses

Changes in environmental factors such as wind, headwind, or sun alter running economy by increasing resistance and air temperature. In addition, heat stress can improve running economy by inducing peripheral vasodilatation in highly trained long-distance runners (Périard et al., 2021). Body mass loss, cardiovascular and thermal strain, and air temperature-adjusted running economy were assessed during prolonged exercise in the heat in marathon runners. Despite similar sweat losses measured during exercise in the heat, marathon runners achieved the same skin temperature without an increase in their cardiovascular strain after exercise; thus, free water intake rather than cardiovascular strain

may be a biomarker for sudden physical collapse among elite marathon runners (Andrade et al., 2023). After completing a marathon, some runners are at increased risk of exertional heat stroke. The heat state and subsequent collapse may be due to an increase in cardiovascular strain, along with symptoms of dehydration and hyperhidrosis, although different mechanisms may affect these symptoms. Furthermore, it has been suggested that runners experience increased cardiovascular strain; however, they develop hypothermia after finishing the marathon due to the angiogenesis-induced sweating response.

Cardiac overload defines endurance sports. It is related to the left ventricle (LV) and left atrial enlargement, increased relative wall thickness, and LV mass. Prior research has shown that left atrial size correlates with IL-6 levels primarily in patients with atrial fibrillation. One widely-accepted theory postulates that at exercise, the changes of the pulmonary circulation in relation to the systemic circulation present a lower rate of decrease in vascular resistance; hence, the stroke work at aerobic exercise necessary to maintain a sufficient flow rate is more demanding for the right ventricle than for the left one, thereby explicating both the greater acute and chronic impact of marathon running on the structure and function of the right ventricle (RV). The right ventricle is considered more susceptible to fatigue after exercise, and, according to hemodynamic theory, fatigue is brought about by increased volume and pressure workload on the right ventricle, in addition to increased exercise volume and intensity (Tsarouhas et al., 2022). Furthermore, the study by Papić et al. (2023) examines the morphological and functional characteristics of the right heart in elite Serbian triathletes and reveals significant adaptations resulting from prolonged endurance training. Compared with untrained individuals, triathletes exhibited higher values of right ventricular diameter (RVEDD), right atrial volume (RAvol), and right ventricular wall thickness (RVWT), indicating right-heart remodeling. However, systolic function, measured by tricuspid annular plane systolic excursion (TAPSE), remained unaffected and within normal limits. These findings emphasize the importance of monitoring athletes' hearts, as adaptations to endurance training can mimic pathological conditions, and highlight the need for regular cardiac evaluations to ensure the well-being of both professional and recreational athletes.

2.4.4 Age and Experience Effects

Another factor linked to pacing is age. Younger males, particularly those under 30, exhibit irregular pacing patterns. This means they have higher initial running speeds and greater decreases at the end of the race, which could be related to younger, less experienced males. They may lack a strategy to maintain the right pace, leading them to adopt the wrong pace and resulting in higher fatigue at the end of the race. This is different from older males, who have the same finishing times as elite runners, especially in slower running groups (Oficial-Casado et al., 2022).

In addition, older athletes, despite being over 60 years old, have shown variability in pacing that is associated with long exposure to low-speed efforts and the accumulation of fatigue at long race times, rather than with early aggressive race pace. Furthermore, differences in pacing stability by sex have been identified in the literature, showing that female athletes exhibit more stable pacing across different age groups. (Oficial-Casado et al., 2022). This

relates to physiological characteristics that may favorably influence fatigue countermeasures during exercise. The role of experience in relation to pacing stability has also been identified as a critical factor in developing more refined pacing strategies. Athletes with experience running in previous long-distance races or with a high level of training have shown a more even pacing distribution, with fewer losses in the second half of the race. The study on pacing stability in different marathons has shown a close relationship between pacing stability and performance category/racing experience. This has also shown the importance of pacing strategies tailored to age and performance categories to avoid fatigue-related performance losses and potential injuries (Oficial-Casado et al., 2022).

The literature shows that several socio-demographic variables play an important role in determining running performance. Yang et al. (2022) compared the gender, age, and running pace of nearly 73,000 Hangzhou half- and full-marathon finishers (2016–2019). Men outnumbered women, especially in full marathons, and ran faster. Shorter races were faster, but older runners, especially in full marathons, were slower. The biggest influences on performance were gender and ethnicity, but performance differences between men and women diminished with distance and age. The study shows how gender, age, and race distance affect marathon performance, offering insights into training and equipment.

Compared to other endurance sports, the impact of age on half-marathon performance was different (Sterken, 2005). It has been demonstrated that age-related declines in endurance performance did not happen prior to the age of 50, with mean marathon race times being the same for the age groups 20–49 years, while age-related performance declines for the subjects aged 50–69 years only ranged from 2.6–4.4% per decade (Leyk et al. 2007). According to these findings, most older athletes retained a high level of physical plasticity, supporting the theory that lifestyle determinants had a significantly greater effect on functional ability than age (Leyk et al., 2007). Before age 55, there was no discernible age-related decline in performance; after that, only a slight decline (Leyk et al., 2010). Rather than biological ageing, sedentary lifestyles were the primary cause of declines in middle-aged performance (Leyk et al. 2010). In conclusion, half-marathon runners were 40–44 years old on average, and their best performances occurred before age 35–40.

2.5 Role of Environmental Factors in Pacing Strategies

2.5.1 Distance

The 42 km or 21 km of road, which constitutes a marathon or half marathon, represents a distance that is within the capabilities of a majority of individuals, but for which performance output is highly variable. Although most individuals who prepare specifically for the event and complete the distance could improve their personal best through effective training methods, an initial understanding of the physiological and psychological mechanisms involved in pacing is an advantage (Haugen et al., 2022). Most obviously, enhanced performance can be demonstrated in race situations through an understanding of human limitations and pacing strategies. There is an increasing popularity of mass-participation endurance events. Of these, distance running combines aerobic exercise with a natural competitive environment, in which individuals of all abilities can participate

(Hughes et al., 2018). Personal interest in running, therefore, involves numerous recreational practitioners and a small number of high-performance athletes (Casado et al., 2021). However, the average performance level, event difficulty, duration, and the associated physiological, biomechanical, and psychological variables together determine the relevance of running (Boullosa et al., 2020).

It is not surprising that elite athletes focus more on tactical strategies, since differences exist between teams and athletes in both absolute and relative competitiveness. Environmental factors also affect risk exposure, which establishes constraints or opportunities for strategic decisions. In this context, this discussion focuses on empirical development strategies. The focus of the experiment reported here is to compare the pacing strategies used by professional and amateur athletes at the split lines every 5 km in marathon and half-marathon races. Since pacing strategy reflects how an athlete chooses to budget their resources during a competition, the distribution of an athlete's energy in relation to the distance of a race, the experimental setting involves a competition between individual athletes, pairs, or teams on a fixed course against established written rules, and that are run in known, partially controlled, and monitored environmental conditions, where the introduction of a controlled variable is difficult or impossible and where risk to participants in the decision process is intrinsic (Casado et al., 2021).

For competitive runners, it is necessary to reduce the time required to complete the race distance as much as possible. According to race distance, races are divided into short distances (100, 200, and 400 m), middle distances (800 m, 1500 m, and 3000 m), and long distances (5000 m and 10000 m). Budget events include aerobic endurance events, such as middle- and long-distance races, but strength was also needed to step up the pace, break away from groups, and sprint in the final stretch. For instance, races covering distances of 5000 m and 10,000 m are well determined by runners' aerobic fitness. Therefore, the oxidative system is the primary energy source (Tatte et al., 2022).

2.5.2 Temperature and humidity

Observed that in a women's marathon performed at European temperatures (9.4–18.7 °C), more erratic pacing was found when the runner was under overlooked conditions (high-temperature-humidity index, THI) compared to favorable conditions (Renberg & al., 2014). However, other studies did not observe any difference in pacing under European temperate conditions with varying humidity (Mantzios et al., 2022). In an Ironman in Germany (13–26 °C), triathletes showed more variable pacing at high THI. Hot conditions with high temperatures are associated with detrimental health outcomes, whereas in humid conditions, sweating and subsequent evaporation serve as cues for athletic thermoregulation (Ebi et al., 2021). High ambient temperature and THI are often considered the major environmental factors that athletes have taken into account when pacing carefully in marathon races over the past years. When ambient temperature is significantly high, the long-term physiological strain/confusion hypothesis occurs; the nervous system or muscles are at risk of depletion and require greater self-regulation (Cramer et al., 2022). To reduce hyperthermia and its adverse effects, athletes slow down to reduce increases in muscle temperature and/or surges in antidiuretic hormone (ADH).

2.5.3 Altitude

Classification of altitude is presented as sea level, low altitude - greater than 500m but less than 2000m, moderate altitude - greater than 2000m but less than 5500m, and high altitude - greater than 5500m. The time required at moderate altitudes up to 2300m is 12-14 days (Levine & Stray-Gundersen, 1997). However, Wyatt (2014) noted that there is significant fluctuation in recommendations for enhancing performance at high altitude, ranging from arrival 24 to 48 hours before competition to 3 months of exposure to high altitude. International professional athletes used altitude to gain ergogenic acclimatization. At moderate altitudes, an athlete can achieve hypoxic exposure of at least 12 hours a day for at least three weeks to achieve the necessary and advantageous effects. The design of a training program has always been a challenge for optimal adaptation during a competitive season. Therefore, there is a need to systematically organize and execute a traditional periodized training program, taking into account the short- and long-term goals and the physiological changes associated with altitude that may affect the athlete's readiness for competition (Tatte et al., 2022).

2.6 Related studies

Analyzing the available literature on pacing strategies of athletes, elites, and even amateur runners in marathon and half-marathon races, the authors observed a series of advancements in the knowledge concerning the optimal pacing strategy to utilize when training or competing, within the last decade, utilizing this information in an optimal manner to perfect an athlete's performance during these events.

2.6.1 Association between Physiological Factors and Running Performance

In Kruger's research titled "Racing patterns of elite and non-elite male Two Oceans marathon runners", published in 2025, the focus was on the elite and non-elite male runners in the 56-kilometer Two Oceans Marathon, determining and comparing the pacing strategies they used. The limited research on pacing in ultramarathon events, despite its essential role in optimal endurance performance, guided this study's focus. Kruger used secondary data from the Two Oceans Marathon race database, split times recorded across the four race segments, and calculated each runner's running speed (kilometers per hour) and average pace. The research is a retrospective observational study involving 25,315 elite and non-elite male runners who participated in races between 2007 and 2019. After that, the participating members were categorized into eight groups, A-H, based on performance and finishing time. The Generalized Linear Mixed-Effects Model (GLMM) was used to evaluate differences in pacing between the groups. The outcomes of the research showed that even though all groups lowered their pace in the first three segments of the race and increased in the last segment, the elites were able to maintain a stable pace, while the non-elites had a varying pace throughout the whole competition; therefore, showing that a stable pace is directly related to a better performance. This study underlines tele-anticipatory factors, which are the factors that influence the athlete's subconscious brain to adjust effort and pacing strategies according to what it anticipates the exercise to be in a manner that maintains the person's physiological abilities to finish it, including prior experience, pacing,

training, and methods of coaching endurance runners, and how they can be improved. This work provides the basis for subsequent research by describing various physiological changes and conditions, such as muscle pain, fatigue, and perceived exertion (RPE), that might affect an athlete's endurance performance prediction (Kruger, 2025).

Using this understanding, Davies et al. (2016), in their research titled "Effect of Environmental and Feedback Interventions on Pacing Profiles in Cycling: A Meta-Analysis," published in 2016, undertook a meta-analysis of previous studies to establish the impacts of environmental and feedback-related factors on pacing mechanisms on pacing profiles in cycling, a sport activity that is closely related to running. Given that pacing strategies are influenced by physiological, psychological, and environmental factors and that their exact impact is unknown, a systematic evaluation was conducted to establish clarity. The authors used previous studies on pacing strategies and their determinants, followed by data extraction on power output, segmented performance (at the start, middle, and end of the trial), and feedback and environmental conditions. The meta-analysis included studies that used a self-paced exercise protocol, reported power output variance, included control and intervention groups, and provided a clear description of the feedback provided or withheld, as well as segmented time-trial data. Their results suggest that pacing is a self-paced activity and is related to a variety of multiple synoptical and physiological processes. They present a number of theories, namely the tele-anticipatory theory and the psychobiological model, that explain how intrapersonal and extra personal factors, such as duration knowledge and past experience, shape pacing strategies. The detailed assessment provides a broad picture of the pacing process and shows that different aspects should be considered in endurance sports (Davies et al., 2016).

In the research titled "Cardiopulmonary responses and muscle strength influence running performance parameters differently at different slopes", published in 2023, Hingrand et al. aimed to analyze the cardiopulmonary responses and the strength of the muscle and their contribution to the performance in running and incline conditions. Data were collected using a treadmill test at three different slopes (1%, 10%, and 25%) and included measurements of gas exchange, VO₂max, maximal aerobic speed (MAS), and maximal aerobic ascensional speed (MaaS). This experimental study included 13 participants with varying performance levels, divided into two groups: performance and recreational. The participants completed seven testing sessions, including three tests of maximal aerobic speed, three endurance tests at 100% MAS, and one test of muscle strength. The findings indicated that ascensional speed is less reliable than heart rate for controlling exercise intensity across various slopes.

In a study by Cleveland (2011), trained distance runners were tested for core function and half-marathon performance after 8 weeks of core training. Core stability and run time were tested pre- and post-test in 24 runners, split into a core training group and a control group. The core training group improved running time by a slightly greater amount than the control group, but the difference was not statistically significant. The improvement in core strength and stability was uneven and not significant between groups. The study found that core training improves core strength and stability but not half-marathon performance.

In Ristanović et al.'s research titled "The pacing differences in performance levels of marathon and half-marathon runners", published in 2023, the focus was on the pacing strategies and their differences in marathons and half-marathons, with respect to the level of performance of the runners participating. Pacing is an essential factor in running; it is the expenditure of energy throughout a run, which is why the strategy differs with the distance. Data were collected from the official results of the Vienna City Marathon between 2006 and 2018, the division of the races into five segments, and estimates of the average change in speed and its variation. This observational, retrospective study used a sample of 208,760 racers, 75,492 in a marathon and 133,268 in a half-marathon, divided into four groups based on performance: High-level (HL), Moderate-high (MHL), Moderate-low (MLL), and Low-level (LL). In addition, the analysis of the data was according to sex, race type, and race segment. The findings of this research indicate that the runners in the Low-level group had the highest variability, with 7.9% in male marathon runners, 5.83% in female marathon runners, 6.05% in male half-marathon runners, and 5.49% in female half-marathon runners. However, in the High-level group of runners, the pace was nearly even: in marathons, 4.14% in men and 3.16% in women, and in half-marathons, 2.97% in men and 2.77% in women.

Therefore, publications by Hingrand et al. (2023) & Ristanović et al. (2023) review the physiological and neurophysiological foundations of pacing and the role of slope gradient, metabolic costs, and gender differences on pacing behaviors. These studies provide insight into monitoring and using physiological profiles in relation to pacing strategies, where further research is needed to understand how athletes can pace themselves in light of their initial values, internal and external loads, and race conditions (Hingrand et al., 2023; Ristanović et al., 2023).

In continuing with the examination of pace, Nikolaidis et al., in their study titled "The Effect of Sex and Performance Level on Pacing in Duathlon", published in 2018, focus on the differences in sex and performance in pacing in duathlons. Despite the duathlons' growing popularity, few studies examine how performance levels affect pacing strategies. Data were collected from Powerman Zofingen and ITU Powerman Long Distance Duathlon World Championships' official database, by measuring the time it took each participant in each part (the first run, the bike, and the second run), in addition to the time of transition, and the relative time, in percentage, each segment took. This observational, retrospective analysis used a sample of 6,671 male and female finishing participants from 2003 to 2017, segregated into quartiles, with Q1 being the fastest and Q4 the slowest. After that, the pacing was compared across these quartiles, focusing on the following variables: sex, performance level, and distance. As a result, a direct relation was found between discipline and performance level, with pacing trends being similar across both sexes and distances. They identified and described sex differences in pacing behaviors of male and female athletes and introduced the importance of physiological factors in performance. As such, this study adds to the knowledge on how gender and performance level might help in ascertaining pacing patterns and will benefit coaches and athletes desiring optimal race performance (Nikolaidis et al., 2018).

More specifically, in another study, titled "Pacing of Women and Men in Half-Marathon and Marathon Races", published in 2019, Nikolaidis et al. investigated the pacing

differences between half-marathon and marathon race runners and identified the difference in pacing according to sex. Moreover, the lack of studies comparing marathons and half-marathons and the pacing strategies applied led to this study. Data were collected using the Ljubljana 2017 race's official results, the split time of the five race segments, and the average change in speed (ACS) to indicate the pace of the participants, who were 7,258 half-marathon runners and 1,853 marathon runners. Furthermore, in this observational retrospective study, the pace of participants was analyzed across race segments, and distance and sex were compared. The findings of this study showed that half-marathon runners had an average change in speed of 4.10% in women and 4.09% in men, while marathon runners had a greater average change in speed, with 5.71% pace variability. Moreover, marathon runners had end spurts at the end of the race, while half-marathon runners did not have these spurts. Overall, half-marathon runners were more stable and even with their pace than marathon runners, with a barely noticeable difference between men and women. This study contributes to understanding pacing and underscores the importance of sex- and distance-specific interventions (Nikolaidis et al., 2019).

Furthermore, Fernandes and Maldonado in their research titled "Against Negative Splitting: The Case for Alternative Pacing Strategies for Elite Marathon Athletes in Official Events", published in 2023, focused on whether negative splitting strategy is in fact the optimal strategy for an optimal performance for elite marathon runners, or if positive splitting better, with the fact that pacers provide advantages that influence the pacing strategy used. Data were collected using Computational Fluid Dynamics (CFD) to calculate aerodynamic drag effects, conduct race simulations to compare various pacing strategies, and model the energetics of runners and pacers. They provide an example of drafting and discuss its possible utility for energy savings, while raising the possibility of reconsidering pacing strategies based on new knowledge of race dynamics and positioning. Furthermore, this simulation-based analytical study, using an elite marathon runner and pacers, analyzed different pacing strategies and the time it took to finish with each, and assessed the runner's performance while running behind the pacers. The findings of the study indicated that, in fact, positive splitting was a better technique than negative splitting, with the runner completing the phase with the pacer faster by 2.4% to 2.6% and then slowing down afterwards, saving energy early on in the race and augmenting the performance altogether (Fernandes & Maldonado, 2023).

In Jaszczak and Płociniczak's research titled "Optimal strategy for trail running with nutrition and fatigue factors," published in 2025, they further continue the discussion by including the nutritional aspects and considering fatigue in the elaboration of pacing strategies in trail running. The focus was on creating a model to estimate changes in terrain, nutrition intake during the race, and fatigue accumulation, to determine the optimal race strategy. They extend previous frameworks to capture the complexities of long-distance races on uneven terrain, illustrating how strategic nutrition can significantly impact performance outcomes (Jaszczak & Płociniczak, 2025). Data from this research were collected using optimal control theory, specifically the Pontryagin Maximum Principle, which suggests the optimal strategy to lessen the race's finish time. This research combines various variables to test the suggested model in real-world conditions, including race trails, runners' speed, nutrition intake, and fatigue. Finally, the findings of this research indicate

that the model was indeed successful, anticipating the optimal pacing strategies on point and assessing race finish times with slight to no error. This model is a useful tool for coaches, athletes, elites, and amateur runners to plan their pacing strategy before a trail run race.

Gómez-Molina et al. (2017) developed and validated several half-marathon performance prediction equations. In two distinct periods, seventy-eight male half-marathon runners took part. The half-marathon performance equations were developed in Phase 1 ($n = 48$) and validated in Phase 2 ($n = 30$). In addition to half-marathon performance, anthropometric and training-related variables were recorded. Additionally, an incremental treadmill test was conducted, recording biomechanical (contact and flight times, step length and step rate) and physiological ($\text{VO}_{2\text{max}}$, speed at the anaerobic threshold, peak speed) variables. In Phase 1, training and anthropometric factors (Equation 1) may predict half-marathon performance to 90.3%, physiological variables (Equation 2) to 94.9%, biomechanical characteristics (Equation 3) to 93.7%, and a general equation (Equation 4) to 96.2%. These formulas showed a significant correlation between performance and the anticipated time in Phase 2 ($r = 0.78, 0.92, 0.90$, and 0.95 , respectively). When considered from multiple angles, the suggested equations and their validation demonstrated strong predictive power for half-marathon performance in long-distance male runners. Additionally, they improved the predictive performance of earlier research, making them a very useful tool in the training and performance domains.

Lastly, a study titled "Sit-and-Reach Flexibility and Running Economy of Men and Women Collegiate Distance Runners" examined the sit-and-reach flexibility and running economy of men and women collegiate distance runners (Trehear and Buresh, 2009). For this correlational investigation, eight collegiate distance runners—four men and four women were the subjects. The standard sit-and-reach test was used to gauge each subject's flexibility, and running economy was measured during an incremental maximal treadmill test at standardized absolute running velocities (200 and 268 m min^{-1}) identical for all participants regardless of fitness level. Statistical analyses revealed a significant sex difference in sit-and-reach scores ($p < 0.05$) and a significant relationship between sit-and-reach scores and running economy at an absolute velocity ($r = 0.826, p < 0.05$). Because the elastic components in muscles and tendons operate energy-efficiently during the stretch-shortening cycle, the significant association indicates that less flexible distance runners tend to be more economical.

2.6.2 Association between Psychological Factors and Running Performance

In Brick et al.'s study titled "Metacognitive processes in the self-regulation of performance in endurance running", published in 2015, the focus was on the cognitive control when endurance running from a metacognitive perspective, and how it impacts the performance and pace of the runner. Moreover, the metacognition concept, meaning thinking about one's own thinking, has not been properly investigated in the context of endurance running, considering that it is a key factor in elite performance. Data were collected through a semi-structured interview and retrospective reports of the athletes' experiences during training and competition. This qualitative study used a sample of 10 elite endurance runners who participated in an international competition. Furthermore, data were analyzed using

content analysis, and themes related to attentional focus, cognitive strategies, and self-regulation processes were identified. Findings of this research reveal that the most commonly used metacognitive strategies include planning, monitoring, and evaluating performance. 80% of the elite athletes participating used monitoring to regulate their pace, 50% correlated effort with their pace during training, and 40% used pain to regulate their pace. Therefore, this study confirms that metacognitive processes are a key factor in regulating an elite athlete's pace when endurance running and augmenting performance.

In Zach et al.'s research, titled "Motivation dimensions for running a marathon: A new model emerging from the Motivation of Marathon Scale (MOMS)", published in 2017, the concentration was on expanding the use of the Motivation of Marathon Scale (MOMS), which is a scale to measure the factors that most commonly motivate athletes to run, specifically long-distance runs, such as a marathon. Over the past few decades, the number of people participating in marathons has increased substantially, driven by several factors. Data for this research were collected using a questionnaire distributed to 306 people, both men and women. In this quantitative study, the questionnaire was distributed via e-mail to coaches, during a marathon race to participants, on Facebook, and through other methods. The findings of this research study indicated that the original Motivation of the Marathon Scale is statistically weak and insufficient. The initial exploratory factor analysis (EFA) indicated that life meaning and the achievement of personal goals were more motivating than motives related to appearance and society, but the model was still not sufficiently accurate. Then came the Improves EFA, which was a better statistical fit than the previously suggested models, with key structural changes due to the greater complexity of motivation, creating clear separations and independence among emotional, health, and personal factors. Finally, it became clear that no motives surpass other motivations; however, they vary along different dimensions and include different aspects. This new model aligns with Self-Determination Theory (SDT), which is guided by basic psychological needs for life, including autonomy, competence, and relatedness.

In McCormick et al.'s research, titled "Psychological Determinants of Whole-Body Endurance Performance", published in 2015, the purpose was to identify the psychological interventions that help in enhancing endurance performance, analyze the other psychological factors that influence the performance, and assess the quality of the existing research. The previous psychology guidelines were not based on endurance-specific evidence, which created a gap in understanding mental processes. Data were collected using database searches and studies. This systematic literature review includes studies on athletic or active individuals. The key findings of this research indicate that the most effective psychological interventions are imagery, self-talk, and goal setting, which enhance athletes' performance, as well as perception-of-effort interventions. Moreover, the factor that impairs endurance performance is mental fatigue; verbal encouragement has a positive impact on endurance. Therefore, this study suggests that psychological factors play a crucial role in endurance performance, and skill training can enhance performance.

In Marcora et al.'s research, titled "Mental Fatigue Impairs Physical Performance in Humans", published in 2009, the focus is on whether endurance performance is negatively impacted by mental fatigue, and if the changes in performance are because of physiological

or psychological factors. In previous studies, endurance performance was often explained in terms of physiological factors; recent studies have also shown the psychological impact and mental fatigue. Data were collected using a lengthened attention task to induce mental fatigue; a cycling ergometer time-to-exhaustion endurance task; the Rating of Perceived Exertion (RPE) scale; and physiological measures, including heart rate, blood lactate concentration, and subjective mental fatigue scales. This experimental study included 16 healthy, physically active participants. The process began with participants either completing a mentally fatiguing task for approximately 90 minutes or engaging in a resting activity to create a controlled condition. Next, a cycling time-to-exhaustion test at around 80% VO_2max was performed; both performances were then compared after mental fatigue and under controlled conditions. Finally, the study found that time to exhaustion decreased by approximately 15% during endurance performance after mental fatigue. In addition to the higher perceived effort in the mental fatigue condition, even though the workload was the same in both conditions, there was no substantial physiological difference in heart rate or blood lactate, indicating that the decline in performance was psychological rather than physiological.

In Sun et al.'s research titled "Counteracting mental fatigue for athletes: a systematic review of the interventions", published in 2024, the concentration was on creating a structured analysis of previous studies on methods to neutralize mental fatigue (MF) in athletes, in addition to exploring their impact on sport-specific performance and cognitive skills. According to studies, mental fatigue often has a negative impact, both physically and cognitively, on the athlete's performance in different sports; however, barely any study analyzes ways to mitigate this fatigue. Data were collected from various databases to compile 10 studies on the subject, and analyzed using a systematic review of randomized controlled trials (RCTs). Findings from this study reveal several interventions for mental fatigue, including self-control strategies, nature exposure, mindfulness, and transcranial direct current stimulation (tDCS). These methods of intervention, in fact, aided strength, speed, skill, stamina, and perceptual-cognitive performance, meaning they do, in truth, help with mental fatigue and improve performance.

In Schiphof-Godart and Hettinga's research titled "Passion and Pacing in Endurance Performance," published in 2017, the focus was on how passion types, including harmonious and obsessive, impact endurance sports in exercise behavior, pacing, and short- and long-term decision making. In this way, the psychological passion is intertwined with the neurophysiological drive to understand how to improve performance, avoid overtraining, and mitigate the risks of burnout. Athletes in endurance sports draw on passion as much as on the physiological drive to overcome discomfort. According to the Dualistic Model of Passion, there are two types of passion: harmonious passion, characterized by autonomy, positive emotions, and a balanced life, and obsessive passion, characterized by impulsiveness, negative emotions, and rigid behavior. Data for this research were collected from the literature on the psychological effects of endurance sports and pacing strategies. Therefore, this perspective article discusses psychology, neurophysiology, and exercise in an integrated manner. Findings from this research indicate that harmonious passion leads to a better, more positive long-term impact on the athlete,

with greater focus and reduced risk, while obsessive passion leads to higher stress levels and impaired concentration, as well as long-term issues like burnout.

In Rubaltelli et al.'s research titled "Emotional Intelligence Impact on Half-Marathon Finish Times", published in 2018, the concentration was on the emotional intelligence of the runners to indicate whether higher emotional intelligence can help with a better performance in half-marathon races, in order to regulate emotions during the run. Emotional intelligence involves sensing, using, understanding, and managing emotions in a healthy way, which in turn helps regulate effort during an endurance run. Data for this research were collected using a Trait Emotional Intelligence Questionnaire, the finish times from official race results, and self-reported data collected a day before the event. In this research, Italian half-marathon runners completed questionnaires, and questionnaire scores were then compared with their finish times to test the direct and indirect relations between passion and endurance performance in half-marathon running. Findings of this research indicated that higher emotional intelligence trait in the questionnaire led to faster finish times, faster by approximately 5 to 10% than average, while lower emotional intelligence trait led to poorer effort regulation.

In addition to the overall synthesis, in Sakalidis et al.'s (2021) research titled "The impact of cognitive functions and intellectual impairment on pacing and performance in sports", the purpose was to examine how pacing behavior and strategies are impacted by intellectual impairment, using previous studies discussing cognition and its relationship with pacing in sports. It is an intense process that relies on the brain's cognitive functions and includes self-regulation, executive functions, and decision-making, which, to a certain extent, is limited in individuals with intellectual impairment. Data for this research were collected from previous studies and the literature on the topic, and analyzed to inform this study's results and theoretical findings. Finally, the findings of this research indicate that athletes with intellectual impairment find it difficult to regulate exercise intensity, maintain pace consistency, and use pacing strategies as effectively as athletes without intellectual impairment.

In related research, Doyenart et al. (2020) reported psychophysiological alterations in amateur runners following a half-marathon. Twenty-two runners (34 ± 4.50 years old; 1.76 ± 0.06 m average height; 73.3 ± 8.19 kg weight) completed a 105-minute half-marathon at above 80% of maximal VO_2 , with 98 m of accumulated altimetry, 23°C temperature, and 48% relative air humidity. Before and after the half-marathon, physiological analyses (heart rate, running pace, energy expenditure), strength tests (hand, shoulder, lumbar waist), and mental health assessments (stress, anxiety, self-esteem, happiness) were conducted. Results from the half-marathon showed significant increases in self-esteem (40%), and happiness (25%). The study concluded that training for a 21-km race in amateur runners led to physical fatigue due to severe physiological and psychological loads, as evidenced by reduced lumbar strength and modest increases in pain and perceived effort. Half-marathon training might boost happiness and self-esteem, perhaps addressing mental health illnesses prevalent in society.

In Serbia, Popov et al. (2019) gathered information from 289 runners (54% male) who had finished at least one endurance running race and investigated their motivation (MOMS), positive and negative feelings, and overall well-being. After applying confirmatory factor analysis to assess the original theoretical MOMS model, suggestions were made for the scale and its latent structure. Results showed that women scored higher on Mental Health Improvement and Physical Health and Condition than men, who scored significantly higher on the Competitive Spirit factor. When it comes to age differences, the younger group of participants (ages 14–35) scored higher on Mental Health Improvement, Physical Health and Condition, and Physical Appearance.

In conclusion, much of the literature cited in this chapter offers a comprehensive review and analysis of the physiological and psychological aspects that underpin pacing strategies in marathons and half-marathon races, suggesting that successful performance in endurance running depends on them. These intangible factors include gender-related physiological differences that affect male and female pacing; environmental conditions such as altitude, heat, and wind, which alter energy expenditure; and individual differences among athletes, including prior training, psychological resilience, and the type of passion that guides the athlete. Furthermore, it is standard that the more experienced the marathon or half-marathon athlete is, the more even and controlled the pace is, and the less variability there is in the athlete's pace. However, more research is needed to enhance training programs for athletes, elite runners and amateur runners to optimize endurance performance during both training and competition.

2.6.3 Synthesis of the Related Research

Recent advances in research on half-marathon and marathon performance have been central to improving understanding of the physiological and psychological mechanisms of endurance, in particular in relation to pacing strategies. Aerobic capacity, running economy and steady pace have been recognized as relevant factors in determining optimal performance. It has been observed that elite athletes tend to keep a more consistent pace during a race, as reported by Ristanović et al. (2023) and Nikolaidis et al. (2019). Other studies have underlined the importance of a combination of factors, including cardiovascular and respiratory functions, muscular fatigue, and environmental conditions, according to Hingrand et al. (2023) and Jaszcak and Płociniczak (2024). These studies suggest that endurance results from a complex interaction of physical processes rather than a single factor. On the other hand, most of these studies rely on laboratory tests or large-scale datasets and often neglect practical, field-based measures such as muscular endurance and sprinting ability, which could be relevant for performance assessment, especially among recreational runners.

In addition, psychological research has demonstrated that endurance performance is a combination of physical ability and psychological factors. The most important methods for pacing and performance include goal setting, self-talk, monitoring one's efforts and visualizing oneself achieving one's goals, as reported by Brick et al. (2015) and McCormick et al. (2015). Mental fatigue, emotional intelligence, and motivation all have direct effects on the effort runners can sustain during the race and on their overall performance, according

to Marcora et al. (2009) and Rubaltelli et al. (2018). Motivation is a complex issue that involves a variety of factors, including health, social, achievement and psychological factors, all of which influence how runners stick to their training and adapt to their performance, according to Zach et al. (2017). These insightful observations support current theories that define perception, motivation, and decision-making as essential to the regulation of effort in long races, thereby strengthening the models.

Despite these developments, most of the research focuses on the physical and psychological aspects of mental health separately rather than combining them into a single model. Very little research has been done on the relationships among fitness, motivation, and performance in half marathons, especially among recreational runners. In countries like Lebanon, where the number of runners entering endurance races is on the rise, little research has been done on this specific topic.

This study aims to overcome the abovementioned limitations by including motivation and physical fitness markers (muscular endurance, sprint speed and flexibility) within a holistic model to predict half-marathon performance. This study extends reliance on aerobic measures through field testing and motivation scales, thereby providing greater ecological validity for predicting performance in real-life conditions. By focusing on Lebanese recreational runners and examining gender differences, the study offers contextualized insights and contributes to the growing literature on the interplay between physical and psychological factors in endurance performance. The aim of this study is to provide a more complete and realistic approach to predicting recreational runners' performance within the half-marathon distance.

CHAPTER THREE: RESEARCH PROBLEM, PURPOSE, OBJECTIVES AND TASKS

3.1 Research Problem

Although it is well known that pacing is crucial in endurance events, there is no literature on the factors that determine pacing in such races, nor any major research that incorporates both physiological and psychological aspects of pacing during half-marathon races. Certain physiological and psychological factors affect pacing in endurance events. Physiologically, aerobic capacity, muscle fatigue, and fuel utilization affect an athlete's pacing strategy. Some psychological factors that influence pacing in athletes include motivation, perceived effort, and self-regulation. Nevertheless, it is not clear which of these factors contributes most to pacing decisions in half-marathon races, and there is limited literature supporting the synthesis of various aspects of pacing, including physiological and psychological factors. Thus, by conducting an extensive quantitative analysis encompassing both physiological and psychological aspects of pacing, this paper could address this gap in the literature. Moreover, the general concept of half-marathon events in specific countries, such as Lebanon, and in the Middle East region has not been sufficiently developed. Thus, by qualifying the analysis to races in Lebanon, this research will contribute to understanding how these factors affect pacing strategies in marathon events.

In conclusion, this research aims to address a gap in the literature regarding the integration of the physiological and psychological dimensions of pacing strategies in half-marathon races. By focusing on the specific context of Lebanon and the Middle East region, this study will contribute to a better understanding of the factors that influence pacing decisions in endurance events.

3.2 Purpose of the Study

The purpose of this study was to investigate the degree to which physiological factors (muscular endurance, sprint speed, flexibility, and cardiovascular endurance) and motivational factors (health orientation, weight concern, affiliation, recognition, competition, personal goal achievement, psychological coping, self-esteem, and life meaning) predict half-marathon performance and pacing strategy among Lebanese recreational runners. Half-marathon performance was assessed using race time, whereas pacing strategy was assessed using split-based pacing variability derived from Garmin/Strava GPS data. The study also examined whether these physiological and psychological variables differed according to selected socio-demographic characteristics.

3.3 Objectives of the study

1. Measuring Beirut half-marathon race time and split-based pacing strategy among Lebanese recreational runners.
2. Determining the anthropometric measures (Body Height, Body Weight, BMI), and the socio-demographic variables (age, gender, running experience, educational background, and marital status) in Lebanese recreational runners and analyzing how these variables influence performance in half-marathon race time and pacing strategy.
3. Determining how physical abilities influence half-marathon race time and pacing strategy.
4. Determining how motivation influence race time and pacing strategy.
5. Provide useful advice on how coaches can create customized running plans that take into consideration each runner's unique physical and psychological characteristics in order to improve half-marathon performance in Lebanese recreational runners.

3.4 Tasks of the Study

- Defining the Socio-demographic profile of the Lebanese Recreational Runners;
- Defining the Physical Fitness Profile of the Lebanese Recreational Runners;
- Defining the motivational factors of the Lebanese Recreational Runners
- Calculating pacing strategy indicators using split-based GPS data;
- Identifying pacing profiles (positive, negative, or even pacing) among Lebanese recreational runners;
- Examining the predictors of pacing variability and race performance
- Analyzing data using specialized statistical software, SPSS.
- Describing and analyzing the relationships and differences between variables, and interpreting the results;
- Create an optimal model: Physical fitness and psychological factors of the Lebanese Recreational Runners.

CHAPTER FOUR: HYPOTHESES

GH: Physical abilities, sociological and psychological motives, and selected socio-demographic variables significantly influence half-marathon performance and pacing strategy among Lebanese recreational runners.

The supporting hypotheses are:

1. H1: Socio-demographic variables (age, gender, running experience, educational background, and marital status) statistically significantly influence half-marathon race performance and pacing strategy among Lebanese recreational runners.
2. H2: Physical abilities (speed, flexibility, cardiovascular endurance, and muscular endurance) significantly influence half-marathon race performance and pacing strategy among Lebanese recreational runners.
3. H3: Motivational variables (health orientation, weight concern, personal goal achievement, competition, recognition, affiliation, psychological coping, self-esteem, and life meaning) significantly influence half-marathon race performance and pacing strategy among Lebanese recreational runners.

CHAPTER FIVE: RESEARCH METHODOLOGY

5.1 Research Design

This study uses a deductive, quantitative, non-experimental cross-sectional design to analyze real-world scenarios with established theories. Multiple regression techniques assess the relationship between pacing strategies and half-marathon performance, offering insights into both physiological and psychological aspects of endurance racing.

5.2 Sample of Participants

The sample of participants consisted of all runners who completed the Beirut Half-Marathon races in March and May 2025 (2 races). Runners with missing data, such as sex, age, results on any race segment, or race placement, were excluded from the analysis. Ninety recreational runners from the Beirut International Half Marathon were recruited, including sub-elite and amateur runners. The number of participants was determined using, G*Power, where a sample of 90 runners was considered adequate at an alpha level of 0.05, a statistical power of 0.80, and a medium effect size ($f^2 = 0.15$) to ensure sufficient power to detect associations between the predictors and half-marathon performance.

5.3 Data Collection Procedure and Ethical Considerations

Physical fitness tests were administered 3 to 5 days before the Beirut Half Marathon to obtain accurate baseline values and reduce fatigue-related effects during the race. All tests were conducted in the morning, under the same conditions for everyone. To further minimize potential confounding variables, individuals were instructed to avoid strenuous physical activity for at least 24 hours before testing. No tests were done on the day of the event or in the days that followed.

The study was carried out in accordance with the terms of the Declaration of Helsinki, the World Medical Association's (2013) guidelines for physicians performing biomedical research on human subjects, and the ethical board's approval number 524/25-2 of the University of Belgrade's Faculty of Sport and Physical Education (Appendix 1).

5.4 Data Collection Tools

5.4.1 *Physiological data*

- **VO2 max (Cooper test):** The Cooper Test represents a basic standard method which health professionals commonly employ to measure aerobic capacity, together with

cardiovascular health in individuals. The 12-minute walk test was developed in 1968 by Kenneth Cooper to quantify how much walking and running participants do before the time is up. The estimated VO₂max is calculated from the total distance covered during the 12-minute exercise period. The test became widely popular because it does not require special equipment and can be performed by anyone regardless of fitness level. The test is used in sports science, military training, and athletic evaluations to quickly assess the endurance levels (Bandyopadhyay, 2015). Modified equations are validated for the application of CRT in evaluating VO₂max in swimmers and volleyball players of both genders (Bandyopadhyay, 2020). The Cooper 12-min run distance was initially recorded in meters, and the Cooper equation was used to estimate VO₂max. Relative VO₂max was calculated for each individual by dividing the absolute VO₂max (ml/min) by body mass (kg) and group means were calculated.

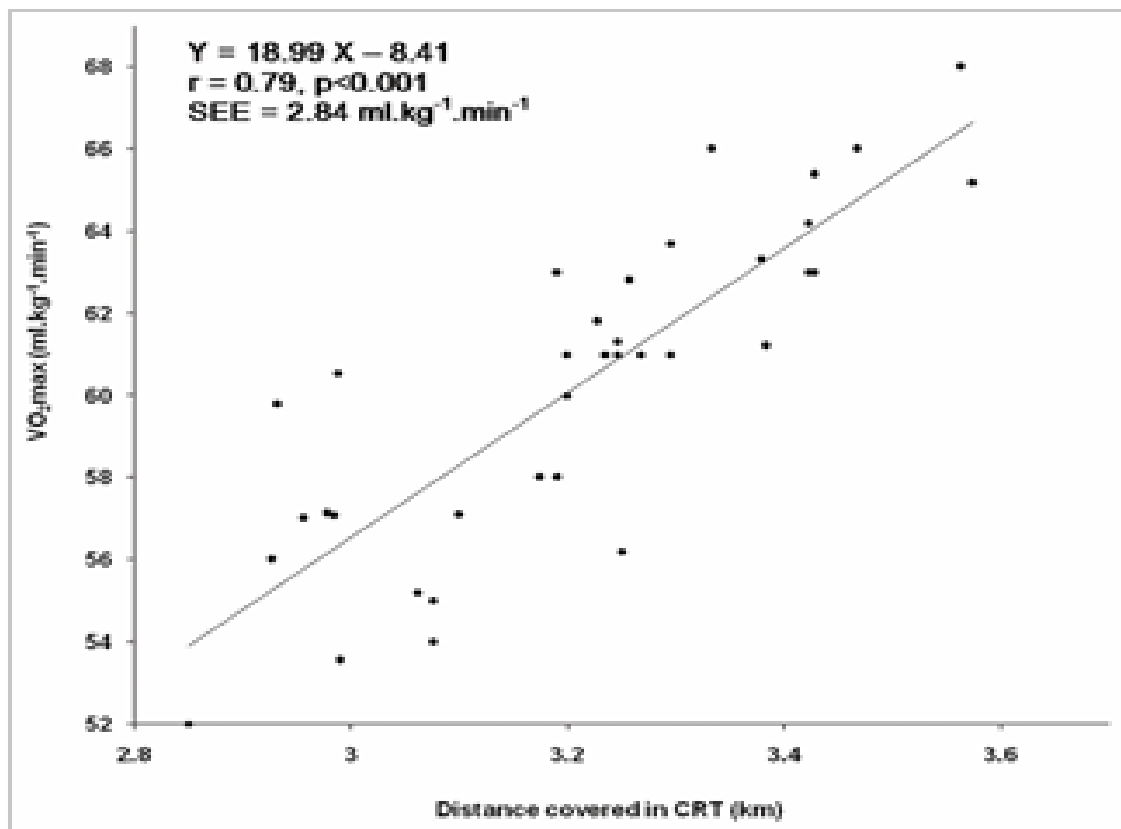


Figure 1. Relationship between VO₂max and distance covered during the Cooper Run Test (CRT) among elite male swimmers.

Cardiorespiratory fitness (VO₂max) was estimated using the Cooper 12-minute run test equation, which has been widely validated for recreational endurance populations. VO₂max was calculated according to the following formula in Figure 2.

$$VO_{2,max} = \frac{\text{Distance (meters)} - 504.9}{44.73}$$

Figure 2. *VO₂max estimation formula*

The AMRAP 1-Minute Test: Participants' muscle endurance was assessed using AMRAP (As Many Repetitions as Possible) field tests for push-ups, sit-ups, and squats. Standard push-ups were performed with full-body girdle support, in a straight body alignment, and with elbow extension. Participants completed as many reps as possible in 60 seconds for each exercise. The authors compared results from standardized testing protocols of push-ups (correct upper-body position and full elbow extension), sit-ups (standard supine starting position with bent knees), and squats (body positioning; legs fully extended). They identified the 1-min AMRAP format as a time-efficient test of muscular endurance and the ability to perform high-intensity exercise in a short period (Türker & Yüksel, 2020).

- **Speed (20m sprint test):** The 20 Meter Speed Test measures ability in a short time, high-effort athletic traits such as acceleration, anaerobic power and speed. Only use this test for athletes who require a strong explosive component in their sport, as it assesses the high-power I would be concerned with. In the test, participants sprint from a stationary start over a 20-meter marked distance as quickly as possible. The timing phase starts at the starting point, and when all participants reach the end of the track, they mark the completion of their test. This recorded time shows better short-distance running ability because a lower time indicates faster performance. The primary performance metric is the time it takes to run 20 meters at full sprint. Lower time points to better speed and superior anaerobic capacity (McMahon et al., 2017).
- **The Sit-and-Reach Flexibility Test** is one of the most popular tests used to examine the flexibility of hamstrings and lower back muscles. The test requires minimal equipment. The test is included in fitness evaluations because it assesses both mobility and flexibility, which support human physical performance during a full range of motion. Test participants should sit on the floor, extending their legs straight forward and resting their feet on a box or Sit-and-Reach apparatus. They stretch their legs without bending their knees, keeping their feet on the ground, to reach the maximum distance on the measurement scale on the box or floor. Measurements are taken in centimeters or inches to find the extent of subject extension beyond the baseline mark. The appropriate technique is important as it gives precise measurement results and protects users from harm (Zanevskyy et al., 2017).



Figure 3. *Standard Sit-and-Reach Test Using a Flexibility Box*

- **Broad jump test:** This test is designed to measure explosive leg power & coordination. Most importantly, the test is simple and does not require special equipment, so it can be performed by literally anyone, regardless of fitness level. Participants begin in a standing position with their feet shoulder-width behind the start indicator. Participants coordinate their arms with their leg power to cover as much distance as possible in the jump. The test consists of jumping out; the jump must land with both feet together to be counted as valid. The measuring device starts from the starting line and goes to the nearest even plane on which their bodies touch the ground (usually their heels). Correct jump technique still depends on injury prevention (Zhu et al., 2022) and collecting the most accurate measurements.

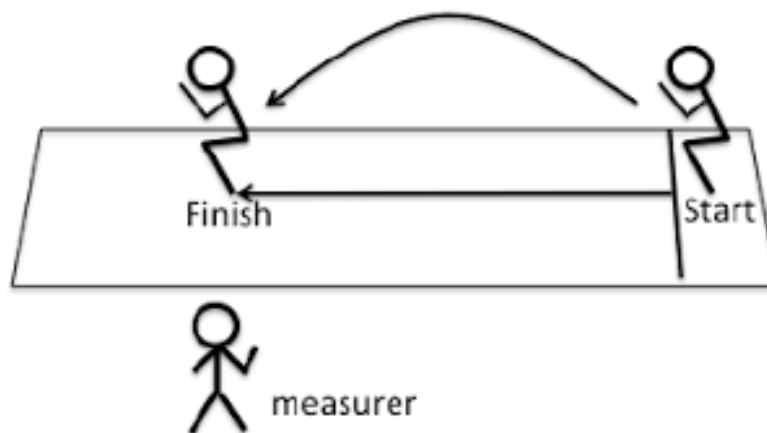


Figure 4. *Standing Broad Jump Test Setup and Starting Position*

5.4.2 *Psychological data*

Psychological data were collected using the Motivations of Marathoners Scales (MOMS) (Masters et al., 1993). The MOMS is a validated tool to measure motivational factors underlying participation in endurance running events. The questionnaire consists of 56 items rated on a 7-point Likert scale, ranging from 1 (not a reason) to 7 (a very important reason). Higher scores indicate that the item is more important for inspiration. The MOMS is divided into four main motivation groups, each with 9 subscales. The first is Physical Health Motives with two subscales: Weight Concern and General Health Orientation. General Health Orientation includes goals such as improving health, avoiding illness, and living longer; Weight Concern includes goals such as controlling weight, losing weight, and maintaining a lean appearance. The second is “Social Motives,” comprising Affiliation (e.g., hanging out with other runners, meeting new people, and feeling like you are part of a group) and Recognition (e.g., receiving respect, compliments, and social approval).

Achievement motives are of two types: competitive achievement (e.g., beating others, doing better than your peers, getting higher places in races) and personal goal achievement (e.g., pushing your limits, hitting your race times, improving your race times). The fourth group is Psychological Motives. This includes Psychological Coping (e.g., reducing anxiety, managing stress, improving mood, solving problems); Self-Esteem (e.g., boosting confidence, self-worth, feelings of accomplishment); and Life Meaning (e.g., finding your life’s purpose, being happy, being at peace with yourself).

Participants were asked to rate the importance of each reason for running a half-marathon. Mean scores were calculated for each subscale, with higher scores indicating more support for the related driving factor. In this study, all nine motivational subscales were examined as possible predictors of how well Lebanese casual runners performed in a half-marathon race and of the differences in their pacing strategies. In Appendix 7, you can find the full form.

5.4.3 *Running Performance*

There were two dependent performance measures in the present study:

- Half-marathon race time (overall performance measure)
- Pacing strategy indicators that have been generated using GPS-based pacing data derived from split times (Garmin/Strava splits).

Pacing strategy variability was calculated using split-based pacing data obtained from Garmin and Strava GPS devices during official 21.1 km half-marathon races. Average running pace (min/km) was extracted across standardized race segments (5 km, 10 km, 15 km, 20 km, and final 21.1 km split). Pacing strategy variability (%) was then calculated using the following equation in Figure 5.

$$\text{Pacing Variability (\%)} = \frac{(\text{Slowest Split Pace} - \text{Fastest Split Pace})}{\text{Average Race Pace}} \times 100$$

Figure 5. *Pacing Variability Calculation*

5.5 Data Analysis

All statistical analyses were conducted using IBM SPSS Statistics 26. The significance criterion was set at $p < 0.05$. Measures of central tendency, variability, and distribution homogeneity were calculated with the mean, standard deviation (SD), minimum (min), maximum (max), coefficient of variation (CV%), and the Kolmogorov-Smirnov test. To infer relationships, find significant differences and make predictions, independent-samples t-tests, ANOVA, MANOVA, Pearson correlation, and Multiple Regression were used.

Pacing variability and pacing progression based on split were determined by race segment. Pacing profiles (i.e., positive, negative, or even pacing) were determined using data-driven descriptive analyses. The socio-demographic, physiological, and psychological variables were then assessed via correlation and regression analyses with respect to pacing strategy indicators. Before running the regression analysis, multicollinearity was assessed using variance inflation factors (VIFs) and tolerance indices. There was no issue with multicollinearity as all variance inflation factors (VIFs) were less than 10 and all tolerance values were greater than 0.10 (Field, 2024).

CHAPTER SIX : RESULTS

6.1 Demographic, Physical, Socio-psychological profiles

6.1.1 Socio-demographic Variables

Tables 1, 2, and 3 present the descriptive characteristics of the sample (n = 90 recreational runners: 45 males and 45 females). The central tendency, variability, and distribution homogeneity measures were presented through the mean, standard deviation (SD), minimum (min), maximum (max), coefficient of variation (cV%), and Kolmogorov-Smirnov test for anthropometric, physiological, and psychological variables.

The group was middle-aged (average 39.7 ± 11.0 years). Around half of the runners were single (46.7%). Most of them reached university-level academic standards (91.1%). The average half-marathon race time was $2:06:13 \pm 0:24:38$ hours, which shows a recreational performance level. All socio-demographic results are shown in Tables 1 and 2.

Table 1. Socio-Demographic Characteristics of the Lebanese Recreational Runners (N = 90)

Variable	N	%
Gender		
Males	45	50.0
Females	45	50.0
Marital Status		
Single	42	46.7
Married	39	43.3
Divorced	6	6.7
Other	3	3.3
Education		
University	82	91.1
High School	8	8.9

cV: Coefficient of variation. KST: Kolmogorov-Smirnov Test

Table 2. *Descriptive Statistics and Normality of Continuous Socio-Demographic Variables (N = 90)*

Variable	Mean	SD	Min	Max	cV	KST
Age (years)	39.9	11.2	19	70	28.1	0.200
Running Experience (Years)	5.3	5.7	1.0	35.0	106.8	0.000

6.1.2 Motivational Variables

The socio-psychological variables of the Lebanese Recreational runners presented in Table 3 and measured using the Motivations of marathoners' scales (MOMS) showed moderate to high levels of motivation across most subscales, with notable variability across motivational areas.

Health orientation and personal goal achievement recorded the highest mean scores among the Lebanese runners ($M = 5.5$, $SD = 1.48$, and $M = 5.6$, $SD = 1.53$, respectively). These results suggest that the primary drivers of participation in half-marathon running in this sample were intrinsic and health-related motives. Likewise, the self-esteem subscale demonstrated relatively high values ($M = 5.08$, $SD = 1.83$), indicating that personal confidence, achievement, and self-perception factors are strong motivators for runners.

On the contrary, recognition ($M = 2.8$, $SD = 1.80$) and competition ($M = 2.8$, $SD = 1.80$) recorded the lowest mean scores, reflecting a limited influence of extrinsic and performance-oriented social motives on running behavior. In addition, weight concern ($M = 3.9$, $SD = 1.99$) and affiliation ($M = 3.8$, $SD = 1.95$) demonstrated moderate levels, indicating that body-related motives and social interaction play a secondary role compared to intrinsic drivers.

Psychological constructs such as life meaning ($M = 4.25$, $SD = 2.00$) and psychological coping ($M = 4.33$, $SD = 1.94$) demonstrated moderate means, reflecting the importance of emotional regulation, stress relief, and existential fulfillment as contributive, but not dominant, motives for endurance participation.

In general, these results show that Lebanese recreational runners are mostly motivated by internal factors, such as achieving goals and boosting self-esteem, while external factors, such as competition and recognition, are less important. This is important for understanding how psychological factors affect endurance performance in this group.

Table 3. Arithmetic means, standard deviations, Minimum, Maximum, and normal distribution for Social-psychological variables (MOMS) of the Lebanese Recreational Runners (N=90)

Variable	Mean	SD	Min	Max	cV	KST
Health Orientation	5.5	1.48	1.0	7.0	19.7	0.200
Weight Concern	3.9	1.99	1.0	7.0	17.8	0.200
Personal Goal Achievement	5.6	1.53	1.0	7.0	23.7	0.063
Competition	2.8	1.80	1.0	7.0	16.4	0.085
Recognition	2.8	1.80	1.0	7.0	23.7	0.200
Affiliation	3.8	1.95	1.0	7.0	18.5	0.200
Psychological Coping	4.33	1.94	1.0	7.0	22.5	0.200
Life Meaning	4.25	2.0	1.0	7.0	31.6	0.091
Self-esteem	5.08	1.83	1.0	7.0	28.4	0.071

cV: Coefficient of variation. KST: Kolmogorov-Smirnov Test

6.1.3 Anthropometric and Physical Variables

Results of the anthropometric and physical characteristics measured in the Lebanese recreational runners (Table 4) showed expected results, with female runners being shorter than males (174.2 ± 7.8 cm vs. 163.5 ± 7.3 cm), resulting in a combined mean height of 168.9 ± 9.2 cm. Similarly, body weight showed a superiority for males over females, with males averaging 76.6 ± 10.4 kg and females averaging 59.6 ± 8.9 kg, resulting in a total mean of 68.1 ± 12.8 kg. The results for height and weight were reflected in the BMI values: males averaged 25.3 ± 3.1 kg/m², females 22.2 ± 2.6 kg/m², and the overall mean was 23.7 ± 3.3 kg/m². Despite the differences in the three overmentioned anthropometric variables, most participants fell within the normal to slightly overweight BMI range. Regarding physical characteristics, males exceeded females in muscular endurance assessments, averaging 39.3 ± 15.9 repetitions in push-up tests, while females averaged 21.3 ± 13.3 . Compared to men, Men achieved an average of 34.4 ± 10.1 in sit-up tests, whereas men reached an average of 30.8 ± 8.5 , with a combined mean of 30.3 ± 17.8 and 32.6 ± 9.5 repetitions, respectively. Regarding squat tests, men exhibited a higher average of 44.6 ± 11.2 repetitions than women, 36.2 ± 9.5 . In terms of flexibility, the sit-and-reach test showed female dominance (28.1 ± 8.6 cm) over males (24.6 ± 10.7 cm), with a combined mean of 26.4 ± 9.8 cm. These findings confirm the established female advantage in flexibility. VO₂max was expressed in absolute (L/min) and relative (ml · kg⁻¹ min⁻¹) terms. Absolute VO₂max was greater in males (2.7 ± 0.4 L/min) than in females (2.35 ± 0.3 L/min); however, relative VO₂max, normalized to body mass, was a more appropriate predictor of aerobic endurance performance. Relative VO₂max was calculated for each participant before averaging across groups. Because endurance-running performance is strongly influenced by body mass, relative VO₂max values are considered more appropriate for comparing aerobic fitness between sexes. As for the broad jump, results showed that men established significantly greater lower-body explosive power, attaining a mean distance of 214.6 ± 33.5 cm, compared with women, whose mean was 162.2 ± 24.1 cm; reflecting an overall sample mean of 190.9 ± 38.9 cm.

In terms of race performance, males finished the half-marathon significantly faster than females (average race times $1:56:41 \pm 0:20:15$ vs. $2:15:45 \pm 0:25:08$) with a total sample mean race time of $2:06:13 \pm 0:24:38$. These results suggest that male athletes are more likely to outperform female runners in the contemporary data set. As for pacing strategy expressed as the percentage of split-based pacing variability across race segments, both males ($13.5 \pm 8.0\%$) and females ($13.0 \pm 8.1\%$) exhibited similar values with an overall sample mean pacing variability of $13.3 \pm 8.0\%$. Results demonstrate variability in the incidence of pacing strategy profiles among Lebanese recreational half-marathon runners. Even though males were faster racers and performed better overall, pacing-strategy variability did not differ significantly between sexes across the whole race. The descriptive results demonstrated considerable disparities between the sexes in body anthropometric measurements and physical fitness performance. Men often possess superior strength, power, and aerobic capacity, while women use a comparable pacing strategy and have enhanced flexibility. These useful patterns provide a foundation for additional statistical analysis to investigate performance determinants and gender disparities.

Table 4. Arithmetic means, standard deviations, and normal distribution for the Anthropometric and physical variables) of the Lebanese Recreational Runners (N=90)

Variable	Males (M+SD)	Females (M+SD)	Total (M+SD)	KST
BH (cm)	174.2±7.8	163.5±7.3	168.9±9.2	0.200
BM (kg)	76.6±10.4	59.6±8.9	68.1±12.8	0.200
BMI	25.3±3.1	22.2±2.6	23.7±3.3	0.017
Push-ups	39.3 ± 15.9	21.3 ± 13.3	30.3 ± 17.8	0.012
Sit-ups	34.4 ± 10.1	30.8 ± 8.5	32.6 ± 9.5	0.000
Squats	44.6 ± 11.2	36.2 ± 9.5	40.4 ± 10.7	0.200
Sit and reach	24.6 ± 10.7	28.1 ± 8.6	26.4 ± 9.8	0.000
Cooper (m)	2679 ± 343	2343 ± 299	2511 ± 384	0.000
VO ₂ Max relative (ml · kg ⁻¹ min ⁻¹)	48.6±7.7	41.1±6.7	44.9±8.1	0.200
VO ₂ max absolute (L/min)	3.72 ± 0.78	2.45 ± 0.57	3.06 ± 0.73	0.200
Broad Jump	214.6±33.5	162.2±24.1	190.9±38.9	0.071
21 k Race Time (H)	1:56:41± 0:20:15	2:15:45± 0:25:08	2:06:13± 0:24:38	0.200
Pacing Strategy	13.5± 8.0	13.0± 8.1	13.3±8.0	0.000

BH: Body Height, BM: Body Mass, BMI: Body Mass Index, KST: Kolmogorov-Smirnov Test

6.2 Relations, Significant Differences, and Predictions across the three multivariate factors.

As mentioned in the data analysis section, the t-test, ANOVA, Pearson correlation, and Multiple Regression Analysis were used to infer the relationships, significant differences, and predictions among variables in Lebanese recreational runners. These analyses were conducted to test the research hypotheses and to reach a decision regarding the research's general hypothesis.

6.2.1 Relations Between Socio-demographic variables and half-marathon performance

Testing: H1: Socio-demographic variables (age, gender, running experience, educational background, and marital status) statistically significantly influence half-marathon race performance and pacing strategy among Lebanese recreational runners.

Continuous variables such as age and running experience were analyzed using Pearson's correlation, while categorical socio-demographic variables such as gender, marital status, and educational background were analyzed using independent t-tests and one-way ANOVA. The combined predictive influence of all socio-demographic variables on half-marathon performance was investigated through multiple regression analysis.

A. Pearson Correlation

(Relationships between Age, running experience as independent variables, and Race time, and pacing strategy as dependent variables)

We use the Pearson correlation matrix to examine the relationships between age, running experience and half-marathon performance. They found no meaningful relationships with pacing strategy across age ($r = .096$, $p = .369$), as well as between pacing strategy and running experience ($r = .008$, $p = .939$), suggesting that these sociodemographic variables were not associated with pacing consistency in gender on paces among Lebanese recreational runners. Race time showed similarly weak, non-significant associations with age ($r = .153$, $p = .150$) and with running experience ($r = .097$, $p = .365$). In conclusion, these data suggest that neither age nor running experience in this sample of runners significantly affected race performance or pacing strategy.

No strong evidence therefore supports H1 because few, non-significant associations were found between socio-demographic variables and race time or pacing strategy. These results suggest that socio-demographic variables have little individual predictive value for half-marathon completion time and should be interpreted alongside physiological and psychological factors. These results are summarized in Table 5.

Table 5. *Pearson correlation coefficients for the relations between age and running experience and both Runners Race time, and pacing (N=90)*

		Correlations	
		Age	Running Experience
Pacing Strategy (%)	Pearson Correlation	0.096	0.008
	Sig. (2-tailed)	0.369	0.939
Race time (Hours)	Pearson Correlation	0.153	0.097
	Sig. (2-tailed)	0.150	0.365

B. Multiple Linear Regression Analysis

Tables 6 and 7 present the results of the multiple regression analysis measuring the effects of socio-demographic variables on half-marathon performance among Lebanese recreational runners. In this section, and in order to understand the results of this analysis, the 1st research hypothesis was divided into two parts: 1) Effect of socio-demographic variables on Race Time, and 2) Effect of socio-demographic variables on Pacing strategy.

1) Effect of socio-demographic variables on Race Time

The dependent variable (race time) was regressed on the predicting variables to test H1. The model, including the five socio-demographic variables, did not predict race time, $F(3, 82) = 2.209$, $p = 0.050$, indicating that socio-demographic variables do not significantly shape half-marathon running time. Moreover, $R^2 = 0.138$ indicates that only 13.8% of the variance in race time was explained by the model, suggesting weak explanatory power. Table 5 shows the summary of this finding. When considered separately, none of the independent variables in the model showed a significant effect on race time ($p > 0.05$). The tolerance and VIF values indicated no multicollinearity concerns among the predictors. These results suggest that socio-demographic factors do not substantially forecast race times among Lebanese recreational runners. Performance results seem to be more significantly affected by other domains (e.g., physiological or psychological aspects) than by background characteristics.

Table 6. Multiple Linear Regression Analysis: Regressing Socio-demographic variables to Race-time (N=90)

		Coefficients ^a				
	Variable	β	t	P-value	Tolerance	VIF
Socio-demographic Variables	Gender	0.060	0.576	0.566	0.957	1.045
	Age	-0.024	-0.194	0.846	0.687	1.456
	Level of education	0.156	1.440	0.154	0.890	1.124
	Marital status	0.223	1.804	0.075	0.679	1.473
	Running Experience	0.182	1.730	0.087	0.937	1.067

Dependent Variable: Race Time

2) Effect of socio-demographic variables on Pacing Strategy

A similar regression analysis indicated that the predictor variables regressed on pacing strategy as the dependent variable increased only non-significantly, $F(3, 82) = 0.210$, $p = 0.957$, indicating that socio-demographic characteristics do not significantly predict pacing strategy overall. On top of that, the $R^2 = 0.012$ illustrates how little (1.2%) variance in pacing strategy is explained by this model.

None of the independent variables (gender, age, educational level, marital status, and running experience) had a significant effect on pacing strategy when considered individually ($p > 0.05$). Tolerance and VIF values also did not raise concerns of multicollinearity among predictors. In conclusion, these results indicate that socio-demographic characteristics have a minimal influence on pacing strategy and are more likely to be determined by other physiological or psychological factors.

Table 7. Multiple Linear Regression Analysis: Socio-demographic variables to Pacing strategy (N=90)

		Coefficients ^a				
	Variable	β	t	P-value	Tolerance	VIF
Socio-demographic Variables	Gender	-0.020	-0.179	0.858	0.980	1.021
	Age	0.067	0.510	0.611	0.692	1.446
	Level of education	-0.003	-0.024	0.981	0.892	1.122
	Marital status	0.060	0.456	0.649	0.680	1.471
	Running Experience	-0.008	-0.074	0.941	0.949	1.054

Dependent Variable: Pacing Strategy

C. Group Differences: T-test: Relationships between Gender and Educational Background as independent variables and Race time, and pacing strategy as dependent variables.

C.1. Gender- based significant differences in race time and Pacing strategy

For testing H1: Socio-demographic variables (age, gender, running experience, educational background, and marital status) statistically significantly influence half-marathon race performance and pacing strategy among Lebanese recreational runners, an independent t-test was conducted to examine gender differences in race time averages across the Lebanese recreational runners.

For gender, the t-test results indicate that males ($M = 1:56:41$, $SD = 0:20:15$) outperformed females ($M = 2:15:44$, $SD = 0:25:08$) in the Beirut half-marathon race, with a large effect size, $t(88) = 3.96$, $p < 0.05$, Cohen's $d = 0.84$. However, no statistically significant gender differences were found in pacing strategy, $t(88) = 0.209$, $p = .835$, Cohen's $d = 0.04$, indicating a trivial effect size. These findings suggest that male ($M = 13.5$, $SD = 8.0$) and female runners ($M = 13.0$, $SD = 8.1$) demonstrated similar pacing strategy variability during the half-marathon race.

C.2. Education-based significant differences in race time and pacing strategy

Results of this section indicate that university-educated runners ($M = 2:05:05$, $SD = 0:24:18$) significantly performed better than high-school educated runners ($M = 2:30:22$, $SD = 0:21:05$) with a moderate effect size in the Beirut half-marathon race, $t(88) = 2.04$, $p = 0.044$, Cohen's $D = 0.43$. There were no statistically significant differences in pacing strategy between groups, $t(88) = -0.298$, $p = .766$, Cohen's $d = -0.07$, i.e., a trivial effect size. These results indicate low variability in pacing strategy between university-educated runners ($M = 13.1$, $SD = 10.9$) and high school-educated runners ($M = 14.8$, $SD = 7.6$).

Results from the t-test partially supported H1, showing that gender was a significant determinant of race time but not of pacing strategy variability. Males, as well as runners with university-level (or higher) education, recorded faster race times, and pacing strategy patterns were similar among groups. These data suggest that socio-demographic factors affect complex overall performance more than pacing regulation.

D. Group Differences: ANOVA: Relationships between Marital Status as independent variables and Race time, and pacing strategy as dependent variables.

D.1. Marital status- based significant differences in race time

Relationships between Marital Status as independent variables and Race time, and pacing strategy as dependent variables.

D.1. Marital status- based significant differences in race time

To examine the differences in race time across marital status categories (single, married, divorced, and other), the one-way ANOVA was conducted. The findings demonstrated statistically significant differences, $F(3, 86) = 2.804$, $p = .045$, $\eta^2 = .089$, indicating a small to moderate effect of marital status on half-marathon race time. This indicates that recreational runners' race times differ across different marital groups.

Using one-way ANOVA, significant differences in pacing strategy were found between groups based on marital status, $F(3, 86) = 4.211$, $p = .008$, $\eta^2 = .128$, indicating a small-to-medium effect. Pacing strategy variability may vary between married and unmarried Lebanese amateur runners. The results are found in Tables 8 and 9.

Table 8. *Marital Status-based Significant Differences across runners in the 21k Race Time (n=90).*

ANOVA						
	Sum of Squares	df	Mean Square	F	P	Eta-Squared
Race time	17328782.052	3	5776260.684	2.804	0.045	0.089

Table Processed by the Author using SPSS

Table 9. *Marital Status-based Significant Differences across runners in the 21k pacing strategy (n=90).*

ANOVA						
	Sum of Squares	df	Mean Square	F	P	Eta-Squared
Pacing Strategy	1336.521	3	445.507	4.211	0.008	0.128

Table Processed by the Author using SPSS

Post hoc pairwise comparisons at $\alpha = .05$ using the Scheffé method did not show significant differences ($p > .05$), but married runners' race times were faster than those of unmarried runners (mean difference = $-0:14:23$, $p = .070$). With a large enough sample, however, an omnibus ANOVA of this data set may simply detect some variability across the factors with no real need for significance correction even among the smaller groups.

Thus, H1 was partially confirmed, as the ANOVA results showed a significant effect of marital status on both race time and pacing strategy. The post hoc analysis, however, failed to identify specific pairwise differences and indicated that marriage has only a limited effect on half-marathon performance.

6.2.2 Relationships between Physical Abilities and half-marathon performance

The Pearson Correlation and the Bivariate Regression analysis techniques were used to test the second hypothesis: H2: Physical abilities (Speed, flexibility, cardiovascular endurance, and muscular endurance) significantly influence half-marathon race performance and pacing strategy among Lebanese recreational runners.

A. Pearson Correlation

Based on race time, the Pearson correlation = .004), suggesting that runners with greater abdominal muscular endurance produced more consistent pacing patterns throughout the half-marathon race. This suggests that core muscular endurance may also facilitate better pacing regulation and enhance resistance to fatigue during endurance performance.

Collectively, almost all physical fitness predictors, except sit-up performance, showed no significant association with pacing strategy variance. Our findings suggest that Lebanese recreational runners use pacing strategies that depend more on innate abilities to regulate pace, as well as on general physical fitness characteristics and fatigue management, and on psychological or experiential factors. n analysis was only partially consistent with H2; although results showed a significant relationship ($p < 0.05$) between sprint performance and $VO_2\text{max}$ with half-marathon race performance for all athletes combined (Table 10), among individual athlete groups, only elite females displayed similar trends in both measures. Pun et al. (2018) found a positive relationship between race time and sprint performance; specifically, significant correlations were observed with the 40m short sprints at both baseline ($r = .272$, $p = .013$), which reflects slower sprint times being linked with longer half-marathon completion times, thus lower endurance performance. Similarly, $VO_2\text{max}$ showed a strong inverse association with race time ($r = -.317$, $p = .004$), suggesting that higher cardiorespiratory fitness was positively associated with faster race completion and endurance exercise performance.

In summary, results demonstrate that, among Lebanese recreational runners, cardiorespiratory fitness and sprinting ability were more strongly associated with half-marathon race performance than muscular endurance, flexibility, or lower-body power.

Analysis of the relationships between pacing strategy and physical fitness characteristics among Lebanese recreational runners using Pearson Correlation Coefficients is shown in Table 9 (Pacing Variability). In contrast, sit-up performance was significantly negatively correlated with pacing strategy variability ($r = -0.319$, $P = .004$).

Table 10. *Relations between the Physical variables, Race time, and Pacing across Lebanese Runners (N=90)*

		Correlations						
		Pushups	Sit-ups	Squat	Flexibility	Sprint	VO ₂ Max	Broad Jump
Race time	Pearson Correlation	-0.026	-0.026	0.052	-0.036	.272*	-.317**	-0.081
	Sig. (2-tailed)	0.816	0.815	0.642	0.747	0.013	0.004	0.487
Pacing Strategy	Pearson Correlation	-0.084	-.319**	0.079	0.178	-0.105	-0.086	0.014
	Sig. (2-tailed)	0.454	0.004	0.479	0.110	0.347	0.445	0.902

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

B. Multiple Regression Analysis

The multiple regression model examining how physical variables could predict race time was not statistically significant, $F(7, 82) = 1.615$, $p = .146$. This means that the physical fitness variables did not significantly predict half-marathon race time among recreational runners in Lebanon. The model explained only 14.3% of the variation in race time ($R^2 = .143$), indicating it wasn't very good at explaining the data.

Individually, none of the physical factors had a statistically significant effect on race time ($p > .05$), but VO₂max ($\beta = .103$, $p = .099$) and 20-m sprint performance ($\beta = -.264$, $p = .121$) were close to being significant. There were also no significant effects on push-ups, sit-ups, squats, sit-and-reach, or the broad jump.

The Pearson correlation analysis showed that sprint performance and VO₂max were significantly associated with race time, but these results only partially align with that. The difference shows that the combined multivariate model lessened the predictive power of each physical variable. This could be because predictors share some of the same variance. Also, the tolerance and VIF values indicated no major multicollinearity issues in the regression model.

Table 11. *Multiple Linear Regression Analysis: Regressing Physical variables to Race-time (N=90)*

		Coefficients ^a				
	Variable	β	t	P-value	Tolerance	VIF
Physical Variables	Push-ups	0.000	0.882	0.381	0.380	2.632
	Sit-ups	0.138	-0.001	0.999	0.691	1.448
	Squats	-0.069	0.947	0.347	0.598	1.673
	Sit and reach	0.297	-0.571	0.570	0.872	1.147
	20 m Sprint	-0.264	1.569	0.121	0.353	2.834
	VO ₂ Max	0.103	-1.671	0.349	0.507	1.974
	Broad Jump	0.000	0.606	0.546	0.439	2.278

Dependent variable: Race Time (RT), Table Processed by the Authors using SPSS

To test H2, the predictor variables were plotted against the dependent variable (pacing strategy). The regression model wasn't statistically significant ($F(7, 82) = 2.073$, $p = .159$), indicating that the physical variables didn't significantly predict how fast Lebanese recreational runners would run. The model explained only 15% of the differences in pacing strategy ($R^2 = .150$), indicating that the independent variable accounted for low variability. Several factors changed the pacing strategy, but only the sit-up performance ($\beta = -0.393$, $p = .002$) and the 20-meter sprint performance ($\beta = -0.568$, $p = .002$) had statistically significant negative effects. This finding shows that a more stable pacing approach during the half-marathon was linked to longer-lasting abdominal muscles and faster sprint times. The squat performance was almost significant ($\beta = 0.263$, $p = .055$), but the push-ups, sit-and-reach flexibility, VO₂max, and broad jump performance were not ($p > .05$). These results are similar to those of the Pearson correlation study, which found a strong link between sit-up performance and changes in pacing strategy. When physical factors are tested together in a multivariate model, the regression analysis shows that sprinting ability can help control pace. Also, the tolerance and VIF values did not indicate any major multicollinearity among the predictors.

Table 12. *Multiple Linear Regression Analysis: Regressing Physical variables to Pacing strategy(N=90)*

		Coefficients ^a				
	Variable	β	t	P-value	Tolerance	VIF
Physical Variables	Push-ups	-0.191	-1.133	0.261	0.380	2.632
	Sit-ups	-0.393	-3.145	0.002	0.691	1.448
	Squats	0.263	1.956	0.055	0.598	1.673
	Sit and Reach	0.136	1.228	0.224	0.872	1.147
	20 m Sprint	-0.568	-3.250	0.002	0.353	2.834
	VO ₂ Max	-0.235	-1.610	0.072	0.507	1.974
	Broad Jump	-0.118	-0.753	0.454	0.439	2.278

Dependent variable: Pacing strategy. Table Processed by the Authors using SPSS

In conclusion, selected physical abilities showed weak but statistically significant ($P < 0.05$) associations with pacing strategy and race performance; therefore, H2 was only partially supported in the present study. Sprint performance and VO₂max were robust predictors of race time, while sit-up endurance and sprint ability significantly predicted pacing strategy variability. Unfortunately, with only a few exceptions, physical variables were not strong predictors of performance, suggesting that pacing regulation can also be based on non-physical factors such as psychological control, fatigue management, and racing experience.

6.2.3 Relationships between motivation and half-marathon performance

As in the previous result subsection, both Pearson correlation and multiple regression analyses were performed to examine the relationships between motives and Beirut half-marathon performance, as measured by race time and pacing strategy, among Lebanese recreational runners. These analyses were conducted mainly to test H3.

H3: Motivational variables (health orientation, weight concern, personal goal achievement, competition, recognition, affiliation, psychological coping, self-esteem, and life meaning) significantly influence half-marathon race performance and pacing strategy among Lebanese recreational runners.

Since the motivational factors include several subscales, the Pearson correlation matrices and multiple regression analyses will be conducted separately for each subscale.

A. Pearson Correlation:

Results from the most motivational subscales' relations with half-marathon performance, measured using the Pearson correlation technique, showed weak, non-significant

relationships among Lebanese recreational runners, with only a few isolated significant associations.

A.1. Relations between motivation and half-marathon performance

The correlation matrix revealed weak, non-significant correlations between the affiliation subscale and race time and pacing strategy variables (Table 13), starting with the correlation between the affiliation subscale and half-marathon performance. These results suggest that motives for social interaction, such as socializing with runners, group identity, and meeting other people, do not have significant relationships with half-marathon performance among Lebanese recreational runners.

Table 13. *Pearson correlation coefficients for the relationships between Affiliation and both Runners Race time, and pacing (N=90)*

		Correlations					
Running Performance / Affiliation		To socialize with runners	To have something in common with people	To meet people	To participate with my family or friends	To share a group identity with runners	To visit with friends
Pacing Strategy (%)	Pearson Correlation	-0.151	-0.094	-0.077	0.057	-0.009	0.013
	Sig. (2- tailed)	0.156	0.376	0.469	0.591	0.936	0.904
Race time (Hours)	Pearson Correlation	-0.098	0.011	-0.032	0.146	0.060	0.062
	Sig. (2- tailed)	0.358	0.919	0.764	0.170	0.576	0.562

***.* Correlation is significant at the 0.01 level (2-tailed).

On the other hand, one item on the recognition subscale ("To make my family or friends proud of me") had a weak but statistically significant positive association with race time ($r = .210$, $p = .047$), indicating that runners who are externally motivated by recognition may perform slightly slower in the race. Other items on the recognition subscale were not significantly correlated with performance outcomes.

Table 14. *Pearson correlation coefficients for the relationships between recognition and both Runners Race time, and pacing strategy (N=90)*

		Correlations					
Running Performance / recognition		To earn respect of peers	To earn the respect of people in general	To make my family or friends proud of me	People look up to me	Brings me recognition	To get compliments from others
Pacing Strategy (%)	Pearson Correlation	0.176	0.039	0.101	-0.011	-0.007	0.061
	Sig. (2-tailed)	0.096	0.716	0.341	0.917	0.951	0.571
Race time (Hours)	Pearson Correlation	0.079	0.072	.210*	0.130	0.039	0.105
	Sig. (2-tailed)	0.458	0.499	0.047	0.222	0.713	0.325

*. Correlation is significant at the 0.05 level (2-tailed).

As for competition, no significant associations were found between the competition subscale and race time or pacing strategy, suggesting that competitive motives, such as beating others or achieving higher rankings, are not directly associated with endurance performance in this sample.

Table 15. *Pearson correlation coefficients for the relationships between Competition and both Runners Race time, and pacing strategy (N=90)*

		Correlations			
Running Performance / Competition		To compete with 4s	To see how high, I can place in races	To get a faster time than my friends	To beat someone, I've never beaten before
Pacing Strategy (%)	Pearson Correlation	0.074	0.139	0.114	-0.019
	Sig. (2-tailed)	0.491	0.192	0.284	0.862
Race time (Hours)	Pearson Correlation	-0.068	0.039	0.160	0.026
	Sig. (2-tailed)	0.525	0.715	0.131	0.804

*. Correlation is significant at the 0.05 level (2-tailed).

Furthermore, the personal goal achievement subscale showed no statistically significant relationships with either race time or pacing strategy. In terms of pacing strategy, some weak positive associations were found; however, these were not statistically significant, indicating that the tendency for runners with higher personal achievement motives to show greater pacing variability throughout the race was only slight.

Table 16. *Pearson correlation coefficients for the relationships between personal goal achievement and both Runners Race time, and pacing strategy (N=90)*

		Correlations					
Running Performance / personal goal achievement		To improve my running speed	To compete with myself	To try to run faster	To push myself beyond my current limits	To see if I can beat a certain time	To make my body perform better than before
Pacing Strategy (%)	Pearson Correlation	0.099	0.100	0.113	0.098	0.071	0.008
	Sig. (2- tailed)	0.354	0.347	0.291	0.359	0.507	0.944
Race time (Hours)	Pearson Correlation	0.027	-0.112	0.024	0.034	0.066	-0.022
	Sig. (2- tailed)	0.802	0.294	0.819	0.750	0.535	0.839

*. Correlation is significant at the 0.05 level (2-tailed).

There was no statistically significant relationship between race time, pacing strategy, and the psychological coping subscale. This means that emotional regulation goals, such as improving mood, reducing stress, or getting away from daily worries, are not directly linked to half-marathon performance among Lebanese recreational runners. Also, confidence-related factors and self-perception were not statistically significantly linked to race time or pacing strategy. This means that confidence- and self-perception-related factors are not associated with differences in endurance performance in this group. Still, there were weak but statistically significant links between race time and two items on the life meaning subscale: “to make my life more purposeful” ($r = .240$, $p = .023$) and “to feel like I belong in nature” ($r = .245$, $p = .020$). It seems that people who run for philosophical or meaning-related reasons might take a little longer to finish races. On the other hand, there were no significant links between pacing technique and motives related to life meaning. These are the results, summed up in Tables 17, 18, and 19.

Table 17. *Pearson correlation coefficients for the relationships between Psychological Coping and both Runners Race time, and pacing Strategy (N=90)*

Correlations										
Running Performance / Psychological Coping		To become less anxious	To become less depressed	To distract myself from daily	To improve my mood	To have time alone to sort	To concentrate on my thoughts	To solve problems	To blow off steam	To get away from it all
Pacing Strategy (%)	Pearson Correlation	0.099	0.1	0.113	0.098	0.071	0.008	0.058	0.092	0.149
	Sig. (2-tailed)	0.354	0.347	0.291	0.359	0.507	0.944	0.588	0.388	0.161
Race time (Hours)	Pearson Correlation	0.181	0.058	0.125	0.123	0.002	0.144	0.117	0.079	0.034
	Sig. (2-tailed)	0.088	0.589	0.240	0.248	0.984	0.177	0.270	0.459	0.748

*. Correlation is significant at the 0.05 level (2-tailed).

Table 18. *Pearson correlation coefficients for the relationships between self-esteem and both Runners Race time, and pacing Strategy (N=90)*

Correlations									
Running Performance / self-esteem		To improve my self-esteem	To feel more confident about myself	To improve my sense of self-worth	It is a positive emotional experience	To feel proud of myself	To feel a sense of achievement	To feel mentally in control of my body	To feel like a winner
Pacing Strategy (%)	Pearson Correlation	0.058	0.153	0.182	0.080	0.108	0.048	0.015	0.130
	Sig. (2-tailed)	0.588	0.150	0.086	0.454	0.309	0.654	0.887	0.222
Race time (Hours)	Pearson Correlation	0.131	0.179	0.097	0.086	0.063	0.140	0.114	0.003
	Sig. (2-tailed)	0.217	0.091	0.365	0.418	0.552	0.188	0.284	0.975

*. Correlation is significant at the 0.05 level (2-tailed).

Table 19. *Pearson correlation coefficients for the relationships between Life Meaning and both Runners Race time, and pacing Strategy (N=90)*

		Correlations						
Running Performance / Life Meaning		To add a sense of meaning to life	To make my life more purposeful	To make myself feel whole	To make my life more complete	To feel a sense of belonging in nature	To have time alone with the world	To feel at peace with the world
Pacing Strategy (%)	Pearson Correlation	0.144	0.130	0.151	0.145	0.069	-0.134	0.112
	Sig. (2- tailed)	0.176	0.222	0.156	0.173	0.518	0.207	0.294
Race time (Hours)	Pearson Correlation	0.116	.240*	0.066	0.085	.245*	-0.027	0.141
	Sig. (2- tailed)	0.278	0.023	0.537	0.424	0.020	0.800	0.184

*. Correlation is significant at the 0.05 level (2-tailed).

According to the Pearson correlation analysis, several clear associations emerged between motivation and performance in a half-marathon. Only a few weak, isolated relationships were found, and they mostly affected race time rather than pacing tactics. These results show that the reasons Lebanese recreational runners engage in endurance running may have a greater effect on their participation and engagement than on their performance.

B. Multivariate Regression Analysis

B.1. Motivation - Race time

The dependent variable (race time) was regressed on the predictor variables representing the subscales of the MOMS scale to test H3. The regression model did not significantly predict race time, $F(9, 80) = 0.453$, $p = .901$, indicating that motives did not significantly explain half-marathon race performance among Lebanese recreational runners. Moreover, $R^2 = .048$ indicated that only 4.8% of the variance in race time was explained by the model, reflecting very weak explanatory power.

When examined individually, none of the motivational predictors demonstrated a statistically significant effect on race time ($p > .05$).

Table 20. Multiple Linear Regression Analysis: Regressing socio-psychological motives to Race time (N=90)

Category	Variable	β	t	P-value	Tolerance	VIF
Psychological variables (MOMS)	Health Orientation	0.103	0.649	0.518	0.472	2.118
	Weight concern	-0.004	-0.025	0.980	0.544	1.839
	Personal goal achievement	-0.134	-0.807	0.422	0.434	2.303
	Competition	-0.021	-0.130	0.897	0.470	2.126
	Recognition	0.134	0.672	0.504	0.301	3.327
	Affiliation	-0.102	-0.676	0.501	0.517	1.932
	Psychological coping	-0.054	-0.293	0.770	0.351	2.847
	Life meaning	0.120	0.559	0.578	0.257	3.887
	Self esteem	0.095	0.474	0.637	0.293	3.413

Race time was tested as dependent variable, *P-value is significant at <0.05

B.2. Motivation - Pacing Strategy

In this section, the regression model did not predict pacing strategy statistically significantly ($F(9, 80) = 0.974$, $p = .467$). This means, therefore, that psychological factors are not a strong enough explanation of between-individual variation in pacing strategy among leisure runners in Lebanon. Also, $R^2 = .099$ indicated that the model could only explain 9.9% of the variation in pacing strategy, suggesting it lacked strong explanatory power.

When examined separately, psychological coping was the only factor that could be statistically significantly associated with pacing strategy ($\beta = -0.378$, $t = -2.112$, $p = .038$). In other words, it meant that runners who were driven to regulate their emotions and cope with stress tended to employ more stable pacing tactics with less fluctuation. Presence of all other potential predictors of desire was not statistically significant ($p > .05$). Table 20 summarizes these results. Table 21 presents the main points of this result.

Table 21. Multiple Linear Regression Analysis: Regressing socio-psychological motives to Pacing Strategy (N=90)

Category	Variable	β	t	P-value	Tolerance	VIF
Psychological variables (MOMS)	Health Orientation	0.014	0.092	0.927	0.472	2.118
	Weight concern	0.132	0.916	0.362	0.544	1.839
	Personal goal achievement	0.021	0.128	0.898	0.434	2.303
	Competition	-0.009	-0.058	0.954	0.470	2.126
	Recognition	0.087	0.449	0.655	0.301	3.327
	Affiliation	-0.205	-1.389	0.169	0.517	1.932
	Psychological coping	-0.378	-2.112	0.038	0.351	2.847
	Life meaning	0.304	1.452	0.150	0.257	3.887
	Self esteem	0.146	0.745	0.458	0.293	3.413

*Pacing Strategy was tested as dependent variable, *P-value is significant at <0.05*

In summary, motivational variables had a limited influence on the running performance or pacing strategy adopted by Lebanese recreational runners during half-marathon running, as shown in the regression analyses. There were no strong motivational indicators of race time. Psychological coping, however, had a small but significant effect on variance in pacing strategies. Even though psychological coping seemed to have a small effect on the initial pacing effort, the overall motivational variables did not have a strong effect on race performance or the variability of pacing strategies. As a result, the combined motivational hypothesis (H3) was not supported. These results show that physiological factors are more important than motivational factors in choosing how well and how fast recreational runners in Lebanon perform in half-marathons.

CHAPTER SEVEN: DISCUSSION

7.1 Introduction

This study aimed to explore the predictive power of physiological factors (Muscular Endurance, Sprint Speed, Flexibility, and Cardiovascular Fitness) as well as psychological motivational factors (Health Orientation, Weight Concern, Affiliation, Recognition, Competition, Personal Goal Achievement, Psychological Coping, Self-esteem, and Life Meaning), on half-marathon performance and pacing strategy among Lebanese recreational runners. Half-marathon performance was measured using race time, and pacing strategy was measured using split-based pacing variability percentages (PV2) calculated from Garmin/Strava GPS race split data, which identify fluctuations in running pace across the 5 km, 10 km, 15 km, 20 km, and 21.1 km race segments.

In particular, the study investigated anthropometric variables (height, weight, and BMI), socio-demographic characteristics (age, gender, experience in running half-marathons, educational level, and marital status), physical parameters, as well as psychological determinants regulating the pace dynamics of half-marathon races. Unlike previous studies that primarily evaluated endurance performance using overall finish time or average pace, the current study adopted a more ecologically valid approach by integrating indicators of split-based pacing strategy with physiological and psychological predictors. Finally, the research aimed to provide practical recommendations for coaches to develop individualized training programs that integrate both physical and psychological characteristics, with the goal of enhancing half-marathon performance and pacing strategy regulation in Lebanese recreational runners. In addition, the study encompassed a general hypothesis GH: Physical abilities, motivation, and selected socio-demographic variables significantly influence half-marathon performance and pacing strategy among Lebanese recreational runners. To test this hypothesis, we had to break it down into four supporting hypotheses as follows: H1: Socio-demographic variables (age, gender, running experience, educational background, and marital status) statistically significantly influence half-marathon performance and pacing strategy among Lebanese recreational runners. H2: Physical abilities (Speed, flexibility, cardiovascular endurance, and muscular endurance) influence half-marathon performance and pacing strategy among Lebanese recreational runners. H3: Motivational variables (health orientation, weight concern, personal goal achievement, competition, recognition, affiliation, psychological coping, self-esteem, and life meaning) significantly influence half-marathon race performance and pacing strategy among Lebanese recreational runners.

Previous studies on endurance running have tended to examine physical and/or psychological determinants, not within a unified analytic framework. Second, while pacing has been identified as a key factor in endurance performance, many have taken average running speed (or finish time) as the outcome of interest, rather than measuring pacing behavior defined by variation in effort distribution between segments during the race (Davies et al., 2016; Schiphof-Godart & Hettinga, 2017). Consequently, this study adds to the literature by modeling these variables into a single composite and, based on previous

contributions, examining the relationships between physical fitness characteristics and motivational factors, along with race-time and split-based pacing-strategy variability, in Lebanese recreational runners.

There is small amount of scientific research on the physiological and psychological profiles of recreational runners, particularly in Lebanon, where participation in endurance events has increased markedly. As such, it is the first study to provide a broader, more applied perspective on endurance performance and pacing strategy in non-elite runners, utilizing validated measures of motivation and field-based fitness testing.

7.2 Demographic, Physical, Psychological profiles

This study gives an overview of the social, physical, and psychological traits of Lebanese recreational half-marathon runners. It highlights the different factors that affect why people take part and how well they perform in endurance events.

Lebanese recreational runners generally have moderate fitness levels, come from diverse backgrounds, and are mainly motivated by internal factors. This aligns with current models of endurance performance, which emphasize how psychological, physical, and experience-based factors shape race outcomes and pacing strategy (Davies et al., 2016; Schiphof-Godart & Hettinga, 2017).

Looking at the social data, half of the 90 runners were single, and 43.3% were married. Most were middle-aged (average age 39.9 years) and had a university degree (91.1%). On average, they had about five years of running experience. Their average half-marathon time of 2:06:13 is typical for recreational runners. These findings are similar to earlier studies showing that most recreational endurance runners are middle-aged, have varied experience, and stable backgrounds (Ristanović et al., 2023; Nikolaidis et al., 2019).

There were clear differences between men and women in physical and body measurements. Men were taller (174.2 cm vs. 163.5 cm) and heavier (76.6 kg vs. 59.6 kg) than women. The average BMI for all runners was 23.7, which is in the normal range. Men did better in tests of muscular endurance, aerobic fitness, and explosive power, while women were more flexible. These results align with known physical differences between men and women and demonstrate how fitness and muscle power affect endurance (Hingrand et al., 2023).

Regarding psychological characteristics, the results showed that intrinsic motives were the dominant drivers of running behavior. Health orientation ($M = 5.5 \pm 1.48$) and personal goal achievement ($M = 5.6 \pm 1.53$) recorded the highest scores among the MOMS subscales, followed by self-esteem ($M = 5.08 \pm 1.83$). Conversely, extrinsic motivations, including competition ($M = 2.8 \pm 1.80$) and recognition ($M = 2.8 \pm 1.80$), exhibited the lowest mean values, whereas affiliation ($M = 3.8 \pm 1.95$) and weight concern ($M = 3.9 \pm 1.99$) displayed moderate levels. Psychological coping ($M = 4.33 \pm 1.94$) and life meaning ($M = 4.25 \pm 2.00$) also showed a moderate motivational effect. These findings suggest that Lebanese recreational runners are primarily motivated by internal factors, specifically health and self-improvement, rather than by external validation or competitive pressures. This pattern

aligns with Self-Determination Theory, which holds that internal motivations such as personal growth, skill, and well-being are key to sustained involvement in endurance sports (Zach et al., 2017).

Previous research also shows that psychological factors, such as goal setting, emotion regulation, and self-evaluation, are important for better endurance performance and pacing (Brick et al., 2015; McCormick et al., 2015).

The moderate coping skills seen in this study support the idea that runners use endurance sports to relieve stress and manage their minds. There is also evidence that mental fatigue can impair endurance performance, regardless of fitness level, underscoring the importance of psychological factors (Marcora et al., 2009).

7.2.1 Race Time

In terms of running performance, however, results indicated that males finished the half-marathon faster than females (1:56:41 and 2:15:45, respectively), suggesting an endurance advantage for males even at the non-elite level. Our results align with reports from other distance-running studies, which show that males have run faster than females at marathon and half-marathon distances (March et al., 2011; Nikolaidis et al., 2018). These disparities are often attributed to physiological benefits in males, including higher aerobic capacity, skeletal muscle mass, and stroke volume, along with greater anaerobic power, which may augment endurance performance and running economy (Hingrand et al., 2023; Snell & Mitchell, 1984). In addition, previous studies have indicated that maximum oxygen uptake (VO_{2max}) and lower limb power are higher in male runners than in females, allowing faster running speeds to be sustained during endurance exercise of prolonged duration (Nikolaidis et al., 2019). Thus, the current gender differences support our hypothesis that sexual physiological factors account for the largest proportion of the half-marathon performance time difference in this task-specific literature.

7.2.2 Pacing Strategy

The average difference in pace variability among Lebanese recreational runners is 13.3%, which is the same as what other studies of endurance running in recreational athletes have found. Elite runners can maintain a steadier, more economical pace in endurance sports (Nikolaidis et al., 2019; Ristanović et al., 2023), whereas recreational and lower-performing runners may change pace more often.

The pacing variability scores in this study are much higher than those reported in top and high-performance endurance athletes. Ristanović et al. found that high-level marathon and half-marathon runners had pacing fluctuation scores ranging from 2.7% to 4.1% in 2023. Lower-level runners, on the other hand, had scores that ranged from 5% to 8%. Similarly, Nikolaidis et al. (2019) found that half-marathon runners typically maintained fairly stable pacing profiles, with average speed changes of only 4%. This was much lower than what was seen in the Lebanese sample.

The fact that leisure runners' pace changes more frequently can be explained by several physiological and psychological factors. Training endurance runners has better aerobic fitness, resistance to tiredness, race experience, and the ability to control their own pace than recreational runners (Brick et al., 2015; McCormick et al., 2015). Theories of endurance performance based on tele-anticipation and psychobiology suggest that to set the right pace, you need to monitor your effort, how tired you feel, and how much energy you're using throughout the race (Davies et al., 2016). So, recreational runners may start runs at too high an intensity and slow down as they get tired, which makes pacing more variable.

7.3 Relations Between Socio-demographic variables and half-marathon performance: Testing H1

The current results partially support H1, showing that socio-demographic factors had selective and inconsistent associations with how well Lebanese recreational runners perform in half-marathon races and with how they pace themselves.

Age and pacing strategy variability did not show a statistically significant relationship ($r = 0.096$, $p = 0.369$), nor did running experience and pacing strategy variability ($r = 0.008$, $p = 0.939$). Also, there was no significant association between age and race time ($r = 0.153$, $p = 0.150$), nor between running experience and race time ($r = 0.097$, $p = 0.365$). These results show that socio-demographic factors alone did not have a strong effect on how well Lebanese casual runners performed in half-marathon races or on how they paced themselves. Previous studies have shown that aging is associated with lower aerobic capacity, neuromuscular efficiency, and fatigue resistance. These changes may affect how you control your endurance and your pacing strategy (Hingrand et al., 2023; Davies et al., 2016).

However, there was no significant relationship between age and race time. This suggests that changes in pacing may compensate for physiological losses associated with aging. These results are similar to those reported by Leyk et al. (2007; 2010), who found that endurance ability remained fairly stable until about age 50.

No significant relationships were found between the number of races run and either race time or pacing strategy variation. Previous research has stressed the importance of experience for regulating pacing and improving endurance (Ristanović et al., 2023), but these results suggest that years of participation may not always reflect how effective planned training is or how good you are at pacing.

The regression analyses showed that socio-demographic factors don't really help explain endurance performance results. Both the race-time and pacing-strategy models had low explanatory power, indicating that socio-demographic factors do not significantly predict half-marathon success when considered together.

In terms of race time, there were significant differences between men and women. Men ($1:56:41 \pm 0:20:15$) did better than women ($2:15:45 \pm 0:25:08$), $t(88) = 3.96$, $p < .05$, Cohen's $d = 0.84$, which means the effect size was large. These results are in line with much

research that has linked differences in endurance performance to physiological factors such as VO_2max and hemoglobin concentration, skeletal muscle mass, and anaerobic power (Nikolaidis et al., 2018). However, there was no statistically significant difference between men and women in the variability of pacing strategies ($t(88) = 0.209$, $p = .835$, Cohen's $d = 0.04$), indicating a very small effect size. During the race, both male ($13.5 \pm 8.0\%$) and female ($13.30 \pm 8.1\%$) runners showed similar patterns of pacing strategy variation.

Also, runners with a college degree ($2:05:05 \pm 0:24:18$) did much better in the race than runners with a high school degree ($2:30:22 \pm 0:21:05$); $t(88) = 2.04$, $p = .044$, Cohen's $d = 0.43$, which means the effect size was moderate. However, there were no statistically significant differences in pacing strategy diversity between educational groups ($t(88) = -0.298$, $p = .766$, Cohen's $d = -0.07$), indicating few differences in how pacing strategies were controlled.

In the same way, marital status did not show any statistically significant changes in either race time or pacing strategy variability ($p > 0.05$). This result might be because different marital groups have different ways of organizing their lives, fulfilling their social obligations, and preparing for races.

Overall, the results show that socio-demographic factors have small and variable impacts on endurance performance and the control of pacing strategies. As a result, H1 was only partly supported.

7.4 Relationships Between Physical Abilities and Half-Marathon Performance - Testing H2.

The present findings partially support H2, as physical abilities, particularly muscular endurance, aerobic capacity, and sprint speed, have a substantial effect on Lebanese recreational runners' half-marathon race performance. However, the effect of these abilities on the pacing strategy appears weaker and inconsistent. The correlation analysis indicated that sprint performance ($r = .272$, $p = .013$) and VO_2max ($r = -.317$, $p = .004$) are the only physical variables significantly related to race time. Indeed, faster sprint times and increased aerobic capacity were associated with better half-marathon performance. Push-ups ($r = -0.026$, $p = .816$), sit-ups ($r = -0.026$, $p = .815$), squats ($r = 0.052$, $p = .642$), flexibility ($r = -0.036$, $p = .747$) and broad jump ($r = -0.081$, $p = .487$) were not significantly related to race time. These results suggest that muscular endurance variables were not significantly associated with half-marathon race time in Lebanese recreational runners. In addition, earlier studies have highlighted the importance of muscular endurance in delaying fatigue, improving running economy, and maintaining force output during prolonged exercise (Hingrand et al., 2023).

Significant correlations were found between sprint performance and race time; athletes with higher neuromuscular efficiency and speed ability achieved better endurance results. These results corroborate the findings of Florence and Weir (1995), who found strong correlations between running velocity and marathon performance.

In contrast, flexibility was not significantly related to race time, indicating that joint range of motion may have limited direct effects on endurance running performance in recreational athletes. This is consistent with previous literature suggesting that flexibility is more important for injury prevention and better movement efficiency than for directly improving endurance performance (McCormick et al., 2015).

The multiple regression model for race time was not significant, $F(7,82) = 1.615$, $p = .146$, with $R^2 = .143$, indicating that the physical variables together accounted for only 14.3% of the variance in race time. Moreover, none of the individual predictors were significant in the multivariate model, suggesting that the physical variables measured in the present study have limited utility in combination for prediction. $VO_2\text{max}$ showed a significant bivariate relationship with race time and was among the strongest physiological correlates of endurance performance (Snell & Mitchell, 1984). Most physical variables were weakly and non-significantly related to pacing strategy variability. Sit-ups showed a large negative association ($r = -.319$, $p = .004$), indicating that runners with higher abdominal muscular endurance adopted a more stable pacing strategy during the race. Regression analysis revealed that sit-ups ($\beta = -0.393$, $p = .002$) and 20 m sprint performance ($\beta = -0.568$, $p = .002$) were significant predictors of pacing strategy variability, but the overall regression model was not statistically significant. These findings suggest that increased core muscular endurance and improved sprinting capacity may be associated with greater pacing stability of recreational runners.

Previous research has highlighted the importance of neuromuscular efficiency, fatigue resistance and running economy for pacing control during endurance events (Haney & Mercer, 2011; Nikolaidis et al., 2019). A stronger core musculature may enhance postural stability and movement economy during prolonged exercise, potentially resulting in lower running pace variability in the latter stages of the race.

These results are in line with current theories of endurance performance, which suggest that pacing strategy is a complex self-regulatory behavior influenced by perceptual, cognitive, physiological, and psychological interactions rather than by physiological capacity alone (Davies et al., 2016; Schiphof-Godart & Hettinga, 2017).

Psychobiological models suggest that a successful pacing strategy entails ongoing regulation of perceived exertion, fatigue management, and energy distribution throughout the race (Brick et al., 2015). The present results suggest that physical abilities have a substantial impact on race performance but have only limited effects on pacing strategy regulation. Thus, H2 was partially supported. Recreational runners might rely more on subjective effort regulation and race experience than on pure physiological optimization when controlling pacing behavior.

7.5 Relationships between motivation and half-marathon performance – Testing H3

The current results do not really support H3, suggesting that motivation has weak, inconsistent effects on the performance and pacing of Lebanese leisure runners in races.

Correlation analyses showed predominantly weak, non-significant relationships between individuals' motivating factors and changes in race time and pacing technique. No significant effects were observed for affiliation-, competition-, or personal-goal-based motivations on endurance outcomes. These results may suggest that social interaction and the desire to compete might have a larger influence on participation and persistence than actual endurance performance (Zach et al., 2017).

One item of recognition, "To make my family or friends proud of me," was weakly positively associated with race time, suggesting that runners with more external motivation may run a bit slower. This finding is consistent with Self-Determination Theory, which posits that intrinsic motivations are more effective than externally controlled motivations in maintaining optimal endurance performance. Two items in the life meaning subscale showed weak positive associations with race time. This suggests that runners motivated by meaning in life and personal satisfaction may place greater value on psychological achievement than on competitive success.

The regression analyses supported these findings. The race-time and pacing-strategy models fit the data poorly, suggesting that sociopsychological factors do not seem to play a large role in endurance event performance.

The regression analyses indicated that sociopsychological reasons are not very good predictors of what will happen. The regression model of the pacing strategy did not do a good job explaining the data ($F(9,80) = 0.974$, $p = .467$, $R^2 = .099$). Individual psychological coping was a strong predictor of pacing strategy variability ($\beta = -0.378$, $p = .038$) but did not make the model significant as a whole.

However, psychological coping was a strong predictor of individual variability in pacing strategy ($\beta = -0.378$, $p = .038$), with little effect of driving factors. This suggests that runners who use running to cope with stress, keep their emotions in check, and think things through may pace themselves more carefully during competition. However, since the overall regression model was non-significant ($F(9,80) = 0.974$, $p = .467$, $R^2 = .099$), this single finding should be taken with a pinch of salt and is not sufficient evidence to support the larger motivational theory.

Motivation factors do not greatly influence endurance performance in recreational runners, especially when physiological training and pacing experience are considered (McCormick et al., 2015; Marcora et al., 2009). This study confirms this. The data show that motivation factors do not significantly influence the performance or speed of Lebanese leisure runners in half-marathon races. Different pacing strategies were highly associated with psychological coping, but total motivation models explained little variance in performance and were statistically insignificant. This suggests that the mixed motivational hypothesis (H3) could not be supported. The body's demands far outweigh the mental demands for success in the half-marathon.

CHAPTER EIGHT: SIGNIFICANCE, LIMITATIONS, AND IMPLICATIONS

8.1 Significance of the Study

Half-marathon running is probably one of the most demanding endurance events, requiring athletes to manage pacing strategy variability throughout the race. The pacing strategies, therefore, have a significant impact on an athlete's performance in these races, with the risk of going out too hard being that the athlete gets fatigued earlier in the event, resulting in poor performance, or going out too slow and never achieving the best time.

By analyzing pacing strategy variability in a major international half-marathon, this research enriched the available data on endurance sports. Thus, the study's results, based on recreational runners, helped identify the most suitable pacing strategy variability profiles for athletes at different performance levels. This information would be useful to coaches, athletes, and other sports science professionals interested in optimizing endurance performance.

Consequently, the findings of this study were of practical importance to athletes and trainers, offering suggestions to improve the effectiveness of training for half-marathoners. This paper aimed to identify physiological and psychological cognitive characteristics that can help athletes decide on their pacing strategy. Coaches can apply this information to develop specific training programs that help athletes address the challenges of endurance racing.

In addition, this study improved the understanding of how physiological, psychological, and demographic factors interact in endurance racing. Analyzing factors such as age, gender, training experience, and athletes' mental training, and their influence on pacing strategy variability, can assist researchers in developing better strategies for success in half-marathon competitions. It can serve as a reference for future studies and be useful to athletes and coaches, offering deeper insights into race strategy.

Hence, this paper discussed the physiological and psychological aspects of pacing strategies in half-marathon races to increase the understanding of endurance sports. By exploring these factors in relation to a major international event, this research will yield useful findings that enhance performance and satisfaction among athletes competing in these demanding events. Consequently, the findings of this study significantly fill a gap in the existing literature on endurance sports, specifically in half-marathon races, and will provide athletic and coaching rubrics for performance enhancement.

This study also enhanced understanding of pacing strategy regulation among Lebanese recreational runners by using split-based GPS pacing analysis rather than relying solely on average pace measures. The observed average pacing strategy variability of $13.3 \pm 8.0\%$ indicates relatively inconsistent pacing patterns among Lebanese recreational runners, compared with the $5.8 \pm 2.8\%$ reported for elite endurance athletes in previous literature.

These findings provide valuable insight into endurance regulation, fatigue management, and pacing consistency during half-marathon competition.

Overall, the results across the three subsections indicate a consistent pattern of weak and non-significant relationships between psychological variables and half-marathon performance among Lebanese recreational runners. In testing the first set of hypotheses (H1 and H2), the findings showed that the examined psychological or behavioral factors (depending on the specific subsection of your study) did not demonstrate strong or consistent predictive power on performance outcomes. Similarly, in the analysis of H3 and H4, both the Pearson correlation and multiple regression results revealed that different motives (affiliation, recognition, competition, personal goal achievement, coping, self-esteem, life meaning) were generally not significantly associated with race time or pacing strategy variability. Only a few isolated, weak, and inconsistent correlations emerged, and the regression models confirmed the limited explanatory capacity of these variables (very low R^2 values), leading to the overall conclusion that all tested hypotheses were largely unsupported.

Taken together, these findings suggest that half-marathon performance in recreational runners is not primarily driven by psychological motives but is more likely influenced by unmeasured factors such as physiological capacity, training status, experience, and pacing strategy. While motivation remains important for initiating and sustaining participation in running, it appears to have a limited direct impact on measurable performance outcomes in this context. Therefore, performance optimization in recreational endurance athletes should not rely solely on motivational factors; rather, it should adopt a more comprehensive, multidimensional approach.

Consequently, some of the non-significant findings observed in the study may be due to uncontrolled confounding, in which socio-demographic or physical characteristics exert stronger influences on performance than motivational constructs. Future research should therefore incorporate these variables into analytical models to provide a more comprehensive and accurate understanding of the determinants of half-marathon performance.

This study expanded endurance sports data by analyzing pacing-strategy variability and race-time techniques in a major international half-marathon. The study's results, based on both professional and recreational runners, helped determine the optimal pacing strategy variability for athletes of varying skill levels. This information would help coaches, athletes, and sports science experts optimize endurance performance.

This study gave athletes and trainers tips for training half-marathoners more effectively. This article sought to identify physiological and psychological traits that can aid athletes in selecting pacing strategy variability. This data can help coaches create endurance-racing-specific training programs.

This study also enhanced understanding of how physiological, psychological, and demographic aspects affect endurance racing. Age, gender, training experience, and mental training of athletes and their effects on pacing strategy variability can help researchers

improve half-marathon strategies. It can be used for future research and provides players and coaches with ideas for racing strategy.

Thus, this study examined the physiological and psychological aspects of pacing strategy variability in half-marathons to improve endurance sports knowledge. It examined these characteristics in relation to a major international tournament to help athletes improve performance and enjoyment. In conclusion, this study filled a gap in endurance sports literature, particularly in half-marathon running competitions, and will provide athletic and coaching rubrics for performance growth.

8.2 Limitations

Notwithstanding these contributions, several limitations should be noted. The comparatively small, culturally specific sample limits the generalizability of the results, and the cross-sectional methodology limits the ability to infer causal links between factors. Furthermore, race time and pacing strategy variability were the main metrics used to evaluate performance; other pertinent physiological or training-related factors that can affect endurance results were not taken into account. Response bias may also be introduced by the use of self-reported motivational measures. Furthermore, the low explanatory power observed in some regression models suggests that performance variability is likely due to unmeasured factors. Therefore, to gain a deeper understanding of endurance performance determinants, future research is recommended to use longitudinal designs, incorporate more comprehensive performance and training indicators, and include larger, more diverse samples.

8.3 Implications

It is recommended that runners, coaches, and researchers take into consideration the following recommendations and consequences, which are based on the findings of this study:

- To better explain performance variability, it is recommended that future studies use physiological evaluations, such as VO₂ max, lactate threshold, and training load analysis.
- To investigate how motivation affects training behavior and performance over time, longitudinal research designs are recommended.
- To improve generalizability across a range of populations and levels of competition, it is recommended that the sample size and diversity be increased.
- To minimize bias and improve accuracy, it is recommended to use objective performance measures alongside self-reported measures.
- Investigate the indirect consequences of motivation, including its influence on adherence to training, consistency, and psychological resilience.

- Construct multidimensional performance models that take into account psychological, physiological, and environmental aspects. For practitioners and coaches, it is recommended that they prioritize structured training programs, pacing tactics, and physical conditioning.
- Motivation should be utilized primarily as a tool to boost engagement and long-term commitment, rather than to directly improve performance.

CHAPTER NINE: CONCLUSION

The aim of this doctoral research was to examine the impact of physiological, psychological, and socio-demographic factors on the half-marathon performance and pacing strategies among recreational runners in Lebanon. The study aimed, through the inclusion of physical fitness characteristics, motivational drivers, and split-based GPS pacing analysis within a holistic research framework, to provide multidimensional knowledge of endurance performance. The data indicated that physiological variables, such as sprint performance, VO_2max , and components of muscular endurance, displayed meaningful relationships with race performance and pacing strategy variability. This was especially true for sprint performance. Recreational runners demonstrated much greater variability in pacing strategies (Mean = $13.3 \pm 8.0\%$) than is typically reported for elite endurance athletes, suggesting an inconsistent pacing profile. Moderate but meaningful correlations were observed between socio-demographic attributes (gender, education level, marital status) and race performance and motivating factors indicated a weak predictive effect on race time and regulation of pacing strategy. The present dissertation aims to contribute to the expanding body of knowledge on endurance running by emphasizing the role of pacing strategy variability as a predictor of endurance regulation in recreational runners. In addition, the study findings highlight the importance of including physiological conditioning, pace regulation and individualized endurance-training protocols for optimal half-marathon performance. Moreover, the study's findings suggest that coaches and recreational runners should focus on neuromuscular training, pacing strategy development, and fatigue management, in addition to aerobic conditioning, during endurance preparation, as the data demonstrate that these are important aspects of endurance training. Future studies should examine the regulation of pacing strategies using longitudinal designs, larger sample sizes, elite athlete populations, and other physiological and environmental variables.

Overall, this dissertation provides a more comprehensive framework for understanding the regulation of endurance performance in recreational half-marathon races and is one of the first multidimensional explorations of pacing-strategy variability among Lebanese recreational runners. Moreover, it is one of the first such explorations.

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Appendices

Appendix 1. Copy of the Ethical Approval Given by Faculty of Sport and Physical Education, University of Belgrade

UNIVERSITY OF BELGRADE
FACULTY OF SPORT AND PHYSICAL EDUCATION
ETHIC COMMITTEE



Subject: Approval of Protocol no. 02-524/25-1 from 08. 04. 2025., submitted by PhD Ivan Ćuk, assistant professor at the University of Belgrade, Faculty of Sport and Physical Education.

Ethics Committee of the Faculty of Sport and Physical Education gives:

APPROVAL

For conducting research entitled „Physiological and Psychological Aspects of Pacing Strategies in Half marathon and Marathon”, planned within the doctoral dissertation of candidate Antoine Abou Mitri. The research will be realized under the supervision of PhD Ivan Ćuk, assistant professor, University of Belgrade – Faculty of Sport and Physical Education.

REASONING

Based on the submitted documents for the research proposal, Ethics Committee of Faculty of Sport and Physical Education, University of Belgrade, concluded that both the concept and the planning of the research and implementation of the obtained results follow the principles in compliance with ethical standards and that it presents no risk to the participants.

Therefore, Ethics Committee of the Faculty approves conducting of the planned research project „Physiological and Psychological Aspects of Pacing Strategies in Half marathon and Marathon”.

In Belgrade, 9.04.2025.

Members

1. PhD Ana Orlić, full professor



2. PhD Marina Đorđević-Nikić, full professor

3. PhD Lidija Moskovljević, full professor

Appendix 2. Published Paper 1



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Muscular Endurance and Speed as Predictors of Half-Marathon Performance in Recreational Runners: A Cross-sectional Study

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ABSTRACT

Background: Despite the growing running culture in Lebanon, recreational runners often lack scientific training guidance, and no studies have examined key fitness predictors of half-marathon performance in this population. **Purpose:** to determine if muscular endurance, flexibility, and speed can predict aerobic capacity, measured by half-marathon race time, and whether these factors differ by gender among Lebanese recreational runners. **Methods:** Ninety amateur men and women completed field tests, including push-ups, sit-ups, squats, the sit-and-reach test for flexibility, and a 20-meter sprint. Race times were recorded from official 21.1 km events. The researchers used Pearson correlations, bivariate regression, and ANOVA to identify which factors predicted race time and to examine gender differences. **Results:** Speed showed the strongest relationship with race time ($r = .559$, $p = 0.000$; $R^2 = .312$), followed by muscular endurance measures: push-ups ($r = -.420$, $p = 0.000$), sit-ups ($r = -.274$, $p = 0.009$), and squats ($r = -.317$, $p = 0.002$). Flexibility did not significantly affect race time ($p > .05$). Gender clearly influenced sprint speed, push-up performance, and race time, with medium to large effect sizes ($\eta^2 = .354, .277$, and $.151$). **Conclusion:** Simple field tests for speed and muscular endurance are practical for predicting half-marathon performance and are influenced by gender-related physiological and pacing differences. These data suggest that adding neuromuscular training to aerobic training may improve endurance, especially for recreational runners without access to advanced testing.

Key words: Cardiovascular Fitness, Running, Muscle Strength, Sex Factors, Physical Conditioning

Appendix 3. Consent Form

Research Project: Physiological and Psychological Aspects of Pacing Strategies in Half marathoners

RESPONDENT'S NAME AND SURNAME:

1. PURPOSE AND DESCRIPTION OF THE RESEARCH

You are asked to participate in a research project aimed at determining the Physiological and Psychological Aspects of Pacing Strategies in Half Marathon runners.

You will be one of 90 participants of half marathon runners, aged 18 +.

Your participation in this project will include taking:

- Anthropometric measurements
- Speed assessment using the 20 m Sprint test
- VO₂ max using the Cooper test
- Amrap test in one min push-ups sit ups squat
- Sit and reach test.
- Broad jump test.
- Moms psychological and sociological questionnaire.

2. CONDITIONS OF PARTICIPATION IN THE EXPERIMENT

All results and information obtained in this study will be treated as confidential. You will not be personally identified as a participant, except by your number/code, which will be known only to the researchers. In the event of injury, you will receive first aid. If you require additional medical attention, you will be responsible for it. You have the right to terminate your participation in the experiment at any time.

3. CRITERIA FOR PARTICIPATION IN THE STUDY

You will not be able to participate as a subject in the study if you suffer from any cardiovascular or neurological diseases, or any injuries that may affect the outcome of the experiment or may be aggravated by your participation.

4. RISK

POTENTIAL RISK: As with any exercise, there is a risk of muscle fatigue and inflammation. However, both factors are transient and without consequences.

5. CONTACTS

If you have any questions regarding the study, please contact Professor Aleksandar Nedeljković or Ivan Ćuk, Faculty of Sport and Physical Education, University of Belgrade (011-3555466). Questions regarding your rights as a participant in the experiment can be directed to the Head of the Ethics Committee of the Faculty of Sport and Physical Education, University of Belgrade (011-3531100).

6. RESPONDENT ACKNOWLEDGEMENT

I have read this document and the nature of my participation, and the requirements, risks and benefits have been explained to me. I am aware of the risks and understand that I may withdraw my consent to participate in the experiment at any time and without any consequences or loss of benefits. A copy of this document has been provided to me.

7. SIGNATURES

Respondent's signature: _____

Respondent's name (print) _____

Date: _____

Appendix 4. Copyright Statement Form

Изјава о ауторству

Име и презиме аутора: **Antoine Abou Mitri**

Број индекса: **2019/5008**

Изјављујем

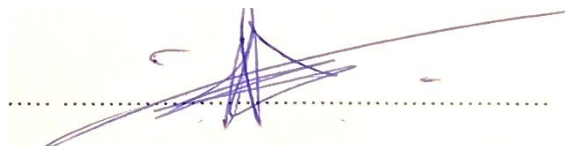
да је докторска дисертација под насловом

Physiological and Psychological Aspects of Pacing Strategies in Half marathon
(Физиолошки и психолошки аспекти стратегије темпа трчања у полумаратону)

- резултат сопственог истраживачког рада;
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Потпис аутора



Appendix 5. Statement on the identity of the printed and electronic versions of the doctoral thesis

Изјава о истоветности штампане и електронске верзије докторског рада

Име и презиме аутора: **Antoine Abou Mitri**

Број индекса: **2019/5008**

Студијски програм: **Експерименталне методе истраживања хумане локомоције**

Наслов рада:

Physiological and Psychological Aspects of Pacing Strategies in Half marathon

(Физиолошки и психолошки аспекти стратегије темпа трчања у полумаратону)

Ментори: др Иван Ћук, доцент
 др Станимир Стојиљковић, редовни професор

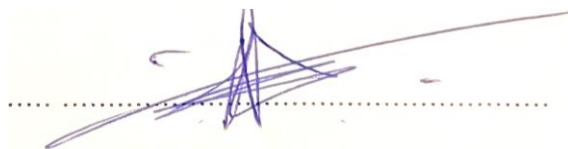
Изјављујем да је штампана верзија мог докторског рада истоветна електронској верзији коју сам предао ради похрањивања у **Дигиталном репозиторијуму Универзитета у Београду**.

Дозвољавам да се објаве моји лични подаци везани за добијање академског назива доктора наука, као што су име и презиме, година и место рођења и датум одбране рада.

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У Београду, 29. маја 2026.

Потпис аутора



Appendix 6. Statement of use

Изјава о коришћењу

Овлашћујем Универзитетску библиотеку „Светозар Марковић“ да у Дигитални репозиторијум Универзитета у Београду унесе моју докторску дисертацију под насловом:

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(Физиолошки и психолошки аспекти стратегије темпа трчања у полумаратону)

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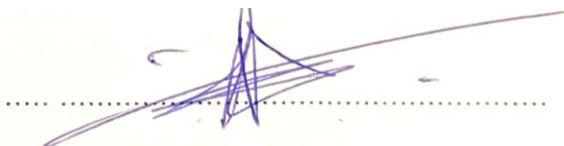
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У Београду, 29. маја 2026.

Потпис аутора



1. Ауторство. Дозвољавање умножавање, дистрибуцију и јавно саопштавање дела, и прераде, ако се наведе име аутора на начин одређен од стране аутора или даваоца лиценце, чак и у комерцијалне сврхе. Ово је најслободнија од свих лиценци.
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Appendix 7. Motivations of Marathoners Scale (MOMS)

The scale, a description, and the scoring are all listed below. You are welcome to use the instrument for research, etc. The citation is:

Masters, K. S., Ogles, B. M., & Jolton, J. A. (1993). The development of an instrument to measure motivation for marathon running: The motivations of marathoners' scales (MOMS). *Research Quarterly in Exercise and Sport*, 64, 134-143.

Psychometric data is available in the above article. Other evidence for validity can be found in the following articles:

Ogles, B. M., & Masters, K. S. (2003). A typology of marathon runners based on cluster analysis of motivations. *Journal of Sport Behavior*, 26(1), 69-85.

Ogles, B. M., & Masters, K. S. (2000). Older versus younger adult male marathon runners: Participative motives and training habits. *Journal of Sport Behavior*, 23(3), 1-14.

Stoll, O., Wuerth, S., & Ogles, B. (2000). Zur Teilnahmemotivation von Marathon- und Ultramarathonluffern. [Participation motives of marathon- and ultra-marathon runners] *Sportwissenschaft*, 30(1), 54-67.

Masters, K. S. & Ogles, B. M. (1998). Cognitive strategies relate to injury, motivation, and performance among marathon runners: Results from two studies. *Journal of Applied Sport Psychology*, 10, 281-296.

Ogles, B. M., Masters, K. S. & Richardson, S. A. (1995). Obligatory running and gender: An analysis of participative motives and training habits. *International Journal of Sport Psychology*, 26, 233-248.

Masters, K. S. & Ogles, B. M. (1995). An investigation of the different motivations of marathon runners with varying degrees of experience. *Journal of Sport Behavior*, 18, 69-79.

Ogles, B. M., Lynn, S. J., Masters, K. S., Hoefel, T., & Marsden, K. (1993-94). Runners' cognitive strategies and motivations: Absorption, fantasy style, and dissociative experiences. *Imagination, Cognition, and Personality*, 13, 163-174.

Ogles, B. M. & Masters, K. S. (1992). Why marathoners run. *Ohio Runner*, 13(11), 5-7, 20.

Please rate each of the following items according to the scale below in terms of how important it is as a reason for why you run. A score of 1 would indicate that the item is "not a reason" for running; a score of 7 indicates that the item is a "very important reason" for running; and scores in-between represent relative degrees of each reason.

Not a Reason A Most Important Reason

1 2 3 4 5 6 7

1. _____ To help control my weight
2. _____ To compete with others
3. _____ To earn respect of peers
4. _____ To reduce my weight.
5. _____ To improve my running speed.
6. _____ To earn the respect of people in general.
7. _____ To socialize with other runners.
8. _____ To improve my health.
9. _____ To compete with myself.
10. _____ To become less anxious.
11. _____ To improve my self-esteem.
12. _____ To have something in common with other people.
13. _____ To add a sense of meaning to life.
14. _____ To prolong my life.
15. _____ To become less depressed.
16. _____ To meet people.
17. _____ To become more physically fit.
18. _____ To distract myself from daily worries.
19. _____ To make my family or friends proud of me.
20. _____ To make my life more purposeful.
21. _____ To look leaner.
22. _____ To try to run faster.
23. _____ To feel more confident about myself.
24. _____ To participate with my family or friends.
25. _____ To make myself feel whole.
26. _____ To reduce my chance of having a heart attack.
27. _____ To make my life more complete
28. _____ To improve my mood.
29. _____ To improve my sense of self-worth.

Not a Reason					A Most Important Reason	
1	2	3	4	5	6	7
30.	_____	To share a group identity with other runners.				
31.	_____	It is a positive emotional experience.				
32.	_____	To feel proud of myself.				
33.	_____	To visit with friends.				
34.	_____	To feel a sense of achievement.				
35.	_____	To push myself beyond my current limits.				
36.	_____	To have time alone to sort things out.				
37.	_____	To stay in physical condition.				
38.	_____	To concentrate on my thoughts.				
39.	_____	To solve problems.				
40.	_____	To see how high, I can place in races.				
41.	_____	To feel a sense of belonging in nature.				
42.	_____	To stay physically attractive.				
43.	_____	To get a faster time than my friends.				
44.	_____	To prevent illness.				
45.	_____	People look up to me.				
46.	_____	To see if I can beat a certain time.				
47.	_____	To blow off steam.				
48.	_____	Brings me recognition.				
49.	_____	To have time alone with the world.				
50.	_____	To get away from it all.				
51.	_____	To make my body perform better than before.				
52.	_____	To beat someone, I've never beaten before.				
53.	_____	To feel mentally in control of my body.				
54.	_____	To get compliments from others.				
55.	_____	To feel at peace with the world.				
56.	_____	To feel like a winner.				

Table 1. General categories, Scales and Sample Items for the Motivations of Marathoners Scales.

General Category

Scale

Sample Items

I. Physical Health Motives

General Health Orientation

to improve my health, to prolong my life, to become more physically fit, to reduce my chance of having a heart attack, to stay in physical condition

Weight Concern

to look leaner, to help control my weight, to reduce my weight

II. Social Motives

Affiliation

to socialize with other runners, to meet people, to visit with friends, to share a group identity with runners

Recognition

to earn respect of peers, people look up to me, brings me recognition, to make my family or friends proud of me

III. Achievement Motives

Competition

to compete with others, to see how high I can place, to get a faster time than my friends, to beat someone I've never beaten before

Personal Goal Achievement

to improve my running speed, to compete with myself, to push myself, to beat a certain time, to try to run faster

IV. Psychological Motives

Psychological Coping

to become less anxious, to distract myself from daily worries, to improve my mood, to concentrate on my thoughts, to solve problems

Self-Esteem

to improve my self-esteem, to feel more confident, to feel proud of myself, to feel a sense of achievement, to feel mentally in control of my body

Life Meaning

to make my life more purposeful, to make myself feel whole, to feel a sense of belonging with nature, to feel at peace with the world

MOMS Scoring Instructions.

Average the items for each of the following nine scales. No items are reverse scored.

Health orientation - 8, 14, 17, 26, 37, 44

Weight concern - 1, 4, 21, 42

Personal goal achievement - 5, 9, 22, 35, 46, 51

Competition - 2, 40, 43, 52

Recognition - 3, 6, 19, 45, 48, 54

Affiliation - 7, 12, 16, 24, 30, 33

Psychological Coping - 10, 15, 18, 28, 36, 38, 39, 47, 50

Life Meaning - 13, 20, 25, 27, 41, 49, 55

Self- esteem - 11, 23, 29, 31, 32, 34, 53, 56

Biography of the Author

Antoine Joseph Abou Mitri was born in 1982 in Hammana, Lebanon. He was raised in his hometown, where he developed a strong connection to nature, physical activity, and community service. He is married to Eliana and is the father of Elay, values that continue to shape his personal and professional dedication to growth and responsibility. Antoine holds a Bachelor's degree in Physical Education and Sports, a Master's degree in Sports Management Professional, and a Master's degree in Sports Research. He is currently completing his PhD in Human Locomotion Sciences at the University of Belgrade, Faculty of Physical Education and Sports, where his academic work focuses on the scientific understanding of human movement, physical performance, and applied training methodologies. Since 2006, he has worked as a Physical Education teacher and professional fitness and bodybuilding trainer, applying scientific knowledge and practical methodology to support athletic development across various age groups and needs. A former professional athlete, Antoine specialized in Greco-Roman and freestyle wrestling. His athletic background later expanded into service roles, becoming a firefighter in 2011 and a rope and mountain rescue trainer. His commitment to leadership and civic engagement is also reflected in his longstanding involvement as a scout leader and community guide. Since 2016, Antoine has been a member of the Faculty of Education at the Lebanese University, Sports Department, where he contributes to academic instruction and practical training. His professional activities extend into outdoor leadership and rope-based adventure guidance, physical training in addiction rehabilitation programs, physical fitness for geriatric populations, and individualized personal training. Antoine's career reflects a consistent guiding principle: the belief in perseverance, discipline, and the importance of continually pushing oneself. Through sport, education, rescue service, and community engagement, he seeks to inspire resilience and purposeful physical development in others.