Review Article

Effective Ultramarathon Pacing Strategies on Road and Trail; A Narrative review

Abstract

Since the inaugural Comrades Marathon in 1921, ultramarathons have witnessed remarkable growth, with a recent surge in both participation and spectator interest. As performance improvement becomes a priority for researchers and ultramarathon runners, understanding pacing strategies, which greatly impact performance, is essential.Pacing strategies for ultramarathon runners can differ substantially based on factors such as age, distance, performance level, and the competition environment. These strategies can help overcome speed drops, especially when running on mountainous or flat terrain, and aid in implementing precooling strategies for improved running. However, no study has fully explored the distinct pacing techniques required for ultramarathons on hilly terrain compared to level roads or tracks.This review aims to provide researchers, coaches, and ultramarathon competitors with a better understanding of pacing processes and strategies across various terrains. It synthesizes effective pacing strategies from existing literature on mountain and track ultramarathons, highlighting similarities, differences, and potential gaps in knowledge. By doing so, this review aims to help ultramarathon participants more effectively comprehend and apply pacing tactics across a range of terrains.

Keywords: competition environment; pacing strategies; performance improvement; terrain differences; ultramarathons

1. Introduction

A footrace that covers a distance larger than 42.195 kilometres and normally takes longer than six hours in duration, is referred to as an ultramarathon [1]. The competitors face challenges such as extreme tiredness, cramps, dehydration, and starvation as they compete over a variety of terrain, including tracks, trails, mountains, deserts, and coastal plains[2, 3]. Since the first "Comrades Marathon" in 1921, ultramarathons have experienced meteoric growth [4, 5]. As a result, ultrarunning has become increasingly popular and competitive [6, 7], with as many as

1,500 runners participating in a single 100-mile race [7]. The majority of athletes that engage in ultramarathons are considered master athletes because they are at least 35 years old and either compete or prepare to compete.When compared to other sports, the performance difference between male and female runners has greatly narrowed, and gains in the overall athletic performance of athletes have significantly increased[5]. Understanding how to increase performance, which is heavily influenced by the pacing techniques of participants [7, 8] is crucial for both scientists and ultramarathoners.The distribution of an athlete's work and effort during an activity, known as pacing, has a significant bearing on the athlete's overall performance. The majority of ultra-endurance racers now use pacing methods, in which they run the first half of the race at a faster pace than they do the second [9]. Pacing techniques for ultramarathoners are very different from one another depending on age, duration, degree of performance, and the surroundings. Off-road runners traverse mountains with thousands of metres of vertical gain in uncertain environments during trail running, which is a growing subcategory of ultramarathoning. One example of this type of race is the Ultra Trail du Mont Blanc, which is 172 kilometres long and has 10,000 metres of vertical gain[10]. On the other hand, road ultramarathons and flat races on track and road provide a consistent setting in which runners can work toward running their fastest times, also known as personal bests, and clock their performances in timed races (such as 12-hour, 24-hour, 48-hour events). The purpose of this review was to examine various methods on a variety of terrains in order to assist athletes in better understanding when certain race strategies should be employed.

Despite the fact that only a few studies have been carried out on the topic, previous research [11]has hinted at the possibility of substantial repercussions for pacing techniques in relation to downhill running, gender, age, uphill running, body mass index, and a variety of other parameters. There is a great deal of variety in pacing techniques, and there has been a great deal of research done on them [12]. However, no analysis has taken into account the varied pacing strategies required for hilly ultramarathons in comparison to flat road and track ultramarathons. This review aimed to synthesize effective pacing strategies in the current literature amongst mountain and track ultramarathons, their similarities and differences, and potential gaps in the literature, in order to better assist researchers, coaches, and ultramarathon participants in coherently understanding the processes and strategies of pacing on a wide variety of terrains.

2. Narrative review

The theoretical framework of this review aims to provide a clear and concise foundation for academics and medical professionals to further expand the existing body of literature in the rapidly evolving field of ultramarathon pacing strategies. The authors conducted a comprehensive search for relevant information using Electronic Databases Premier, Google Scholar, Researchgate, PUBMED, and Web of Science, covering the period from each database's inception until February 1, 2023.

The search focused on pacing research for ultramarathons and employed Boolean operators (AND, OR) in combination with the following MeSH terms and keywords: (("Running"[Mesh]) AND ultra-marathon) OR ultra-marathon) AND "Athletic Performance"[Mesh] AND "Humans"[Mesh]. Studies published in English that examined ultramarathon distances greater than 100 kilometers were considered eligible for further investigation. If a study analyzed multiple distances, it was still included in the review, provided that at least one of the examined distances fell within the specified range.

Studies that were challenging to access, prohibitively expensive, or contained unverifiable references were excluded from this analysis. This rigorous selection process ensures that the review's theoretical framework remains focused on high-quality, relevant research to better understand the pacing strategies in ultramarathons across various terrains.

3. Effective Pacing Strategies

3.1 Significant Speed Reduction

It is typical for runners in an ultramarathon to experience a gradual slowing of their pace as the race progresses. Herding behavior has been found to interfere with the pacing tactics of runners; as the runners in the front of the pack slow down, so do the runners who are falling further and further behind [13]. Studies of pacing in marathons and championship events have shown that lower-level athletes had a faster opening speed compared to their overall race time [14, 15]. This is because lower-level athletes have more time to train and improve their technique. This holds true even if competitors competing at a lower level are able to complete their races in a shorter amount of time. It is crucial to note that multiple prior studies have indicated that having obvious competitors can both enhance an athlete's performance and affect their pacing strategy [16-18].

This is something that should be taken into consideration. It is crucial to note that earlier research have indicated that having visible opponents can influence an athlete's pacing strategy. These two studies evaluated pacing strategies in mass-start events, and it is also vital to highlight that these previous studies have proven this. The physiological effects of different kinds of pacing were studied using a cycle ergometer over the course of a timed 60-minute time trial [19], in which the intensity of the exercise was either held constant or changed. According to the findings of this research project, the test subjects were not subjected to any additional stress response (such as oxygen consumption, average heart rate, anaerobic glycolysis values inside the blood, and perceived exhaustion during the tests) when the intensity was varied by 5%. During the course of the tests, the subjects' aerobic metabolism, average heart rate, lactate levels in the blood, and perceived levels of exertion were all monitored. This allowed for the conclusion to be drawn. This shows that one could anticipate being able to retain the same average power generation despite having moderate changes in intensity, as opposed to when there is an even dispersion of intensity. This is in contrast to the situation where there is an even distribution of intensity. Greater variations in intensity (>10%) appear to create increased physiological stress and, as a result, inferior overall average output power [19]. This is in comparison to maintaining a steady intensity level throughout the workout.

When used to ultramarathons, the term "skeletal muscle damage" describes the race-induced muscle pain that occurs not as a result of muscle fatigue but rather as a result of muscle injury [20]. An ultra-marathon has a significant impact on the skeletal muscles [21]. The downhill portions of the race cause the most muscle damage [22]; specifically, a run of 330 kilometres with an elevation gain of 24,000 metres causes a measurable inflammatory process and swelling in the thigh muscle strength[23]. As a result, injury to the skeletal muscles is a significant issue that needs to be considered by ultramarathon runners.When conducting research on ultramarathon runners, a number of different blood indicators have been used to evaluate the level of damage done to skeletal muscle. Creatine kinase, which is an enzyme that is naturally present in muscles, is ideally suited for the purpose of documenting the damage that an ultra-marathon does to those muscles because of its presence in those muscles. The eccentric mass, such as that that is observed during a mountain ultra-marathon, can result in a significant boost in creatine kinase[24], in addition to pronounced muscle soreness. These results were found in studies conducted by Noakes and colleagues in 1983 and Frey and colleagues in 1994.

According to Carmona et al.'s [25] research, the highest level of creatine kinase activity is reached about an hour after the end of an ultra-marathon. On the other hand, it's probable that the activity will be at its peak between 36 and 72 hours after the occurrence[26]. It is not uncommon for an increase in creatine kinase levels to follow an ultra-marathon, and this increase appears to be proportionate to the length of the event[21, 27]. This increase can be rather frightening. The level of creatine kinase that is produced as a result of running an ultra-marathon that is longer than 308 kilometres is significantly higher than the level that is produced by running an ultra-marathon that is longer than 100 kilometres[28]. The amount of creatine kinase climbed to 35 times its normal level during an ultra-marathon which was 200 kilometres long, and it remained elevated for five days after the race concluded[29]. The level of creatine kinase shot up to 90 times what it was at the commencement of yet another ultramarathon, which was 200 kilometres long [30]. There is a possibility that the creatine kinase levels in the "Badwater" could reach as high as 27,951 U/l [21]. In the "Western States Endurance Run," the creatine kinase concentrations of 216 of the 328 finishers ranged from 1,500 U/l to 264,300 U/l, while the values of 13 of the finishers were greater than 100,000 U/l. Taking this into account results in a completion percentage of 66% [31]. Running ultramarathons is associated with a variety of tissue and organ damage, depending on the location of the damage. The most obvious issue is the discomfort in the muscles. On the other hand, there is evidence that this has a deleterious impact on the cardiovascular system, the liver, the kidney, the bone, the gastrointestinal tract, the immunological system, and the hormone system[11].

It appears that age is an important determinant of running performance in ultra-marathoners[32] and marathon runners [33]. Running performance among male ultra-marathon runners of 100 kilometres was at its peak between the ages of 25 and 35 [34], and it declined beyond the age of 45 [35]. Because of the negative correlation between age and running performance in 100 km ultra-marathons, it may be anticipated that older runners (those who are older than 35-45 years[36, 37]) will slow down more quickly than younger runners (those who are younger than 35-45 years) during the course of a 100 km race. With the presumption that older runners would slow down more than younger runners, this study studied variations in normalized speed and stamina (as a measure for effort dispersion) across segments in male professional and age group 100 km ultra-marathoners in the '100 km Lauf Biel' held in Switzerland [9].

On the other hand, sex is an important factor that can contribute to the speed of a contestant. In past few decades, women have been able to close the gender gap with males, particularly in age group categories in which significantly more women were in the beginning stages of their careers than men [38]. There are a number of factors that can contribute to differences in performance between males and females. Therefore, the disparity between the sexes is at its highest when there are fewer women than males competing, and this is especially true on the shorter ultra-marathon routes [39]. It has been demonstrated that the gap between the sexes stays the same over larger running distances such as 200 as well as 1,000 kilometres, taking into consideration the pattern that has been observed throughout various running lengths over the course of the past few decades. On the other hand, female runners caught up to male runners at shorter running distances of between 50 and 100 kilometres. Due to the fact that this pattern does not follow a linear progression, it is highly improbable that women will catch up to males in the near or distant future, and they will never be able to surpass men [40]. However, it is possible for women to win an ultra-marathon despite the fact that it is traditionally dominated by men. For instance, the Japanese runner Hiroko Okiyama was able to win the "Germanyrun" in 2007 and defeat all of the men [39, 40]. In subsequent research, it will be necessary to determine whether or not women have been able to close the gender gap between themselves and males in older age groups. Women reach their greatest ultra-marathon race time at the same age as men do [34, 35, 41-43]. This indicates that there are no gender differences in the age at which athletes reach their peak performance. The age of the quickest female and male finishers at the annual 100-kilometer ultramarathon was less than 35 years old for both sexes[35]. The best performance was recorded by both males and females at the age of fewer than 40 years old in the 24-hour ultra-marathon running event [43], as well as in the "Badwater" and "Spartathlon" [43].

In the case of interval starts in cross-country races, it was discovered that the athletes use a positive-pacing strategy but that the racers who perform far worse are the ones that get off to the quickest start relative to their own completion times [16]. This was discovered through an examination of these races. This discovery was made possible thanks to the inquiry. The same study that found that the best skiers had a more consistent race with less of a decrease in speed over the curriculum of the race suggested that less skilled skiers should adopt a more even pacing strategy [16]. This recommendation was made after observing how the best skiers had a race that was more even and had less of a reduction in speed over the course of the race. The researchers reached this verdict after noting that the greatest skiers participated in a competition that was more close throughout. Welde et al. (2017) did research on the best male cross-country skiers and found that racers with lower levels of accomplishment lose more time through out course of a race than skiers with higher levels of achievement do. This was one of the findings of their study. In addition to this, they discovered that the speed on the uphill sections reduces less between the first and final circuits, whereas the speed on the easy segments falls more, and that the speed on the easier portions is the most accurate predictor of their performance [18]. It was determined that this was indeed the case. In the course of the competition, there was most certainly increased friction between the skis and the snow, which resulted in a decrease in speed on the gentler terrain. On the other hand, the increased friction had less of an impact on the uphill sections due to the fact that the glide phase was shorter in those sectors. During a 15-kilometer time trial competition, the variances in the topography have less of an impact when comparing the split times of different five-kilometer loops. As a consequence of this, 15-kilometer time trials are an effective method for investigating the pacing features in cross-country trackers across different laps that are otherwise comparable all the way through the race. In addition, the national season opening in Norway is a good opportunity for high-performance level Norwegian cross-country skiers to explore multiple aspects of male elite cross-country skiers' pacing techniques. This is because the national season opener takes place in Norway. This is something that can be done in Norway at the beginning of the national season. The fact that these competitions are played on the same course and with the same number of rounds year after year is a quality that has the potential to be regarded as advantageous. In addition, the vast majority of skiers who have satisfied the requirements to compete in these occurrences do so because the results they achieve in these competitions are utilized to determine whether or not they will be allowed to take part in successive World Cup and Scandinavian Cup competitions. This is true for the majority of skiers.

In conclusion, effective pacing strategies play a crucial role in optimizing performance in ultramarathons and other endurance events. Gradual slowing of pace is a common occurrence among runners, with herding behavior and visible competitors influencing pacing strategies. Higher-level athletes tend to have a more even pacing approach, leading to better overall performance.

Physiological factors, such as muscle damage, also play a significant role in determining pacing strategies. Runners must be aware of the potential for skeletal muscle damage, especially during downhill portions of the race, and adapt their pacing accordingly to minimize injury and maintain performance.

Age and sex are two demographic factors that can impact running performance and pacing strategies. While older runners may experience a decline in performance, it is important to recognize that women have been able to close the gender gap in recent years, with some even achieving overall race victories. As a result, individualized pacing strategies should be developed based on factors such as age, sex, and experience level.

Cross-country skiing research has shown that racers with lower levels of accomplishment lose more time over the course of a race than more skilled skiers. This highlights the importance of adopting a more even pacing strategy to optimize performance. Ultimately, understanding and implementing effective pacing strategies is essential for athletes looking to maximize their potential in endurance events.

3.2 Track Ultramarathons

Both the flat races and the track races are going to be run at very high speeds. A study of people who finished a marathon on a flat course found that the runners who finished the race the fastest kept a consistent pace when the weather was cool but slowed down when the temperature increased during the second half of the race [44]. The mean CV of 6.3% across the first 10 distance segments was comparable to the mean CV (5.4%) recorded by the top 10 elite ultra-runners in the 100-km IAU World Challenge. Segment 11 was removed from the computation because the finish spurt would inflate the mean overall CV considerably [45]. This number is also a significant reduction from the mean CV (16.3%), which was recorded over the same parts of the remaining top 10% of 101-km finishers in both years. These findings concur with earlier studies that found faster athletes exhibit more even pacing than the less successful competitors in time and distance ranging from 100 kilometres ultra-marathon [46] to marathon running [15]. This suggests that similar processes pertaining to regulatory intensity impact the strategy that is utilized in endurance activities of varying durations. The runner adopted a low starting speed instead of keeping up with the faster runners, which is demonstrated by the runner's adoption of a low starting speed rather than sustaining with the faster runners. This, combined with an unusually large end spurt that was 62% above his mean race pace, is potentially the result of an overly conservative-based race strategy. One possible explanation for his reluctance to quicken his pace is that he has a high perception of risk but a low perception of the rewards of doing so [47]. Because the intervals of uncertainty that occur during closed-loop exercises tend to lessen as the activity gets closer to its conclusion [48], the runner may have felt that it was finally safe to go faster, which explains the significant end surge that the runner had. In point of fact, he did not pass the front-runner until some point during the final five kilometres of the race[49].

Elite runners have the functional fitness to push themselves to their limits since they train the majority of their miles at a slower pace. During the medium to peak phases of their training, the finest ultrarunners in the world run at a high intensity, anywhere from three to four times per week on a regular basis. But this strenuous running is done with an extraordinary amount of prejudice and over a variety of different terrains and situations, including flats and hills, roads and trails, short and lengthy intervals[50]. Workouts are carefully monitored and measured from one week to the next. They are able to determine the effectiveness of the training by contrasting a workout from today to the same workout from one month ago.Midpackers generally make one huge mistake. They enter "The Gray Zone" on a regular basis, perhaps even on a daily basis. This is an area of intense aerobic activity that is neither quick enough to be fat burning nor slow enough to receive true fitness advantages. This lukewarm zone impedes development, which leads to injuries and burnout, and since the body depends on stress and relaxation, this zone is lukewarm[48, 50].

In conclusion, both flat and track ultramarathons involve maintaining high speeds, and successful runners often exhibit more even pacing compared to their less successful counterparts. This consistency in pacing is influenced by various factors such as weather conditions, perceptions of risk and reward, and an individual's ability to manage uncertainty during the race.

Elite ultrarunners achieve their fitness by training at a slower pace for most of their miles, engaging in high-intensity workouts three to four times per week during the medium to peak phases of their training. These athletes are highly strategic, taking into account various terrains and conditions while carefully monitoring their progress.

On the other hand, midpackers often fall into "The Gray Zone," an area of intense aerobic activity that provides limited fitness benefits and can lead to injuries and burnout. This zone hinders progress, as the body relies on stress and relaxation for development.

Future research in track ultramarathons should focus on identifying effective pacing strategies, understanding the physiological and psychological factors that impact performance, and providing guidance for athletes to optimize their training and racing strategies.

3.3 Mountain Trail Races

When participating in a mountain ultramarathon (MUM), it can be quite difficult to keep a steady pace due to the numerous changes in altitude, slope, and terrain. In various studies evaluating the 161 km Western States Endurance Run (WSER) was done, it was found that while mountain running speeds vary greatly, the ultrarunner with the least fluctuation in speed is often the most successful. Winners of the WSER would run close behind the lead pack at the beginning, only moving ahead in the middle of the race and slowing down the least [51].In addition, pacing in mountain trail ultra-marathon racing is distinguished by segments of positive and negative pacing [52], and racing speed variations related to the elevation changes [53, 54]. The fastest times are attained when speed fluctuations are restricted [12]. For instance, in the UTMB® (also known as the "Ultra-trail du Mont Blanc"), maintaining a consistent pace throughout the race was positively connected with faster total race times [10]. One of the most important aspects of ultra-marathon running is the prevalence of social contacts and interpersonal relationships during ultra-races. Ultra-races provide the ideal setting for developing these aspects of the sport[55].During an ultramarathon that is held in the mountains, the terrain of the course is the factor that is most likely to have an impact on the pacing decisions that are taken. When compared to the level portions, the participants often run at a slower pace heading uphill and at a faster speed heading downhill [54]. This is in contrast to the flat sections. This stands in contrast to the areas that are flat. It was discovered, for instance, that even an uphill running both had a speed reserve that permitted for an increment in running pace during the final sequence of a mountain ultra-marathon that encompassed 173 kilometres and included both uphill and downhill sections [55]. Additionally, it was found that running even allowed for a speed reserve that enabled a rise in running pace during the final section of the race. Because of this speed reserve, I was able to raise my running pace throughout the last segment of the race. In a similar fashion, the top runners in the age division for 40–44 years old at Switzerland's "100-km Lauf Biel" sped up their pace during the latter stages of the competition. This advancement occurred all the way through the latter stages of the competition (i.e., negative pacing). This was most likely the result of the weather circumstances, in particular, the gradually growing light at dawn and the relatively level track in the last stretch before the finish line [8]. More specifically, the light gets brighter as morning approaches. During a 106-kilometer trail mountain ultra-marathon, the runners had been using a positive pacing strategy in which their speeds slowed down for the first 90 % of the race but sped up during the final 10 percent of the contest [52]. This allowed the runners to finish the race in the fastest time possible. Because of this, the runners were able to cross the finish line in a stronger position. During the "Spartathlon," there was a pace trend that looked like an inverted J; in other words, it is assumed that the inverted J pace pattern was caused by the topography. However, there is a possibility that hasbeen overlooked in certain additional aspects, such as the temperature, the weather, running each day and night, as well as sleeping or napping throughout the night. These are just a few of the other things that spring to mind at the moment. Therefore, the J-shaped pace that was seen in the Spartathlon should be credited to both the route profile and the typical pacing that is prevalent in ultra-marathon running races. These two factors should be considered in conjunction with one another. This conclusion could be drawn as a result of the relatively flat nature of the course profile[56].

In conclusion, maintaining a consistent pace in mountain ultramarathons (MUMs) is a significant challenge due to the frequent changes in altitude, slope, and terrain. Studies on various races, including the Western States Endurance Run (WSER) and the UTMB®, have demonstrated that minimizing speed fluctuations and employing a combination of positive and negative pacing strategies often lead to better race performance.

The terrain greatly influences pacing decisions, with runners generally moving slower uphill and faster downhill. Moreover, factors such as weather conditions, diurnal changes, and race-specific circumstances can also impact pacing strategies. For example, the inverted J-shaped pacing pattern observed in the "Spartathlon" can be attributed to both the course profile and the typical pacing strategies found in ultra-marathon races.

Given the importance of social contacts and interpersonal relationships during ultra-races, further research is warranted to better understand the impact of these factors on pacing strategies and performance in mountain ultramarathons. By gaining deeper insights into pacing strategies, runners can optimize their performance in these physically demanding and challenging events.

3.4 Precooling strategies and pacing performance

Precooling is a common tactic that is used to delay the onset of the devastating effects of exhaustion brought on by heat stress and to increase the amount of time that an individual is able to bear being in an environment that is heating up. The consumption (internal) and application (external) of cold modalities such as air, water, and/or ice, singularly or in combination, instantaneously prior to exercise have become increasingly popular choices over the past three decades as a means of precooling before participating in a sporting event. This trend has been observed worldwide[57].In point of fact, methods that can reduce commencing body temperature prior to activity or lessen the rate of heat boost during exercise have already been found to increase the length of time it takes to reach a critical restricting temperature, which in turn lengthens exercise achievement [58]. This is because techniques that can reduce starting core temperature prior to activity also reduce the rate of heat gain during exercise. [Note: For example, Gonzalez-Alonso and colleagues [58] provided evidence that voluntary exhaustion was attained at the comparably high core (oesophageal; 40.2°C) and muscular (*40.8°C) temperatures as well as subjective assessments of exertion. This was the case regardless of the fact that the initial values had been reduced by a preceding water immersion that had lasted for thirty minutes at a temperature of seventeen degrees Celsius[59]. The researchers found that there was an inverse relationship between submaximal cycling endurance and baseline body temperature. As a consequence of this, precooling greatly improved the participants' ability to engage in physically taxing activities. There has been a significant increase in interest in precooling activities over the course of the previous three decades, with the aim of boosting athletic performance[60]. One of the techniques that can be used to prepare oneself for physical activity by subjecting oneself, shortly before beginning the activity, to cold air, water, or ice. Evidence obtained from a variety of laboratory tests has been regularly used as the impetus for the development of new precooling equipment and processes in the realm of sporting competition[61].

In conclusion, precooling has emerged as a valuable tactic to mitigate the detrimental effects of heat stress and prolong an individual's endurance in hot environments. Over the past three decades, the use of cold modalities, such as air, water, or ice, both internally and externally, has gained popularity as a precooling method before participating in sporting events. This global trend has been supported by evidence that demonstrates the ability of precooling techniques to lower the initial body temperature and decrease the rate of heat gain during exercise, ultimately extending exercise performance.

Researchers like Gonzalez-Alonso and colleagues have shown that precooling can help athletes achieve voluntary exhaustion at comparably high core and muscular temperatures while maintaining subjective assessments of exertion. The inverse relationship between submaximal cycling endurance and baseline body temperature further emphasizes the benefits of precooling in enhancing athletes' ability to perform physically demanding activities. Consequently, the growing interest in precooling over the last three decades has fueled the development of new equipment and methods for its application in the context of sports competition, informed by evidence from various laboratory tests.

4. Limitations

This review has a number of shortcomings due to its nature. To begin, the search criteria disqualified any research that involved other types of endurance sports or running competitions that were shorter than a marathon. Although this was done with the intention of increasing the specificity of the findings with regard to the sport of ultramarathons, it is likely that pertinent data from other fields were missed in the process. Second, though having members of both sexes in each cohort was a requirement for participation, the ratio of males to females in the cohorts was nevertheless skewed in favor of the males, sometimes by a significant amount. This could cast doubt on the reliability of some of the findings.

Moreover, this review did not provide a systematic assessment of the research quality rating and gave a subjective assessment of the aggregated outcomes of research, which range in mountain-based techniques, precooling methodologies, and exercise outcomes. This review was published in 2014. It is challenging to incorporate all of the existing research into a single set of conclusions due to the large variety of research designs, techniques, ambient circumstances, and exercise protocols that are now accessible.

5. Conclusion

This review highlights the growing acknowledgment of sex-related differences in physiology and their potential impact on ultramarathon pacing strategies. However, significant knowledge gaps persist regarding the scope and importance of these differences. The existing literature is dominated by observational studies, with a scarcity of interventional research comparing sex-based ultrarunners, effective ultramarathon pacing techniques, and mountain running.Despite this growing recognition, there is currently insufficient evidence to develop comprehensive guidelines, underscoring the need for more research that considers sex as a significant bivariate factor. In particular, future studies should focus on examining sex differences within physiological responses to various training, dietary, and recuperation regimens. By addressing these gaps in the literature, researchers can contribute to a more robust understanding of sex-specific considerations in ultramarathon performance, paving the way for tailored pacing strategies and training programs that accommodate the unique physiological needs of both male and female athletes.References

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