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# Stability of Running Stride Biomechanical Parameters during Half-Marathon Race

**Javier Olaya-Cuartero , Basilio Pueo , Lamberto Villalon-Gasch * and Jose M. Jimenez-Olmedo**

Research Group in Health, Physical Activity, and Sports Technology (Health-Tech), Faculty of Education, University of Alicante, 03690 San Vicente del Raspeig, Spain; javier.olaya@ua.es (J.O.-C.); basilio@ua.es (B.P.); j.olmedo@ua.es (J.M.J.-O.)

* Correspondence: lamberto.villalon@ua.es

**Abstract:** This study explores the stability of biomechanical parameters of the running stride of male trained athletes during a half-marathon competition. Using a field-based descriptive design, eight male athletes from a local training group were monitored throughout an official half-marathon race under identical conditions, assessing biomechanical parameters including ground contact time (GCT), leg spring stiffness (LSS), vertical oscillation (VO), and stride length (SL) recorded via the Stryd Summit Power Meter. A repeated measures analysis of variance (RM ANOVA) was conducted to detect significant changes in biomechanical parameters as the race progressed. Results demonstrated minimal changes in all parameters, with no significant differences observed for GCT ($F = 0.96$, $p = 0.38$), VO ($F = 0.23$, $p = 0.87$), and SL ($F = 1.07$, $p = 0.35$), and a small ($\eta^2 = 0.004$) yet statistically significant difference in LSS ($F = 5.52$, $p = 0.03$) between the first and second segments, indicating that athletes were able to maintain stable biomechanical parameters throughout the race. The conclusion highlights the need for personalized training programs tailored to the unique biomechanical adaptations and demands of endurance running.

**Keywords:** athletes; competition; Stryd; long-distance running

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## 1. Introduction

Maintaining consistent movement patterns throughout a running event presents a significant challenge [1]. Deviations from these patterns can not only lead to decreased performance but also exponentially increase risk factors and contribute to injuries [2]. Fatigue stands out as one of the major factors behind this performance decrement and the ensuing issues [3]. From a physiological perspective, the metabolic cost of running at a submaximal constant speed is influenced by various factors, including fatigue and associated kinematic alterations [4]. The influence of fatigue on biomechanical parameters in endurance sports has been shown to modify stride frequency (cadence) and length (SL), ground contact time (GCT), vertical oscillation (VO), and leg spring stiffness (LSS), with variations being multiple and variable between athletes and conditions. However, the most relevant variations are primarily found in these parameters [5].

Regarding SL, several authors [6–8] have observed a reduction in fatigued states compared to non-fatigued states. Numerous studies [2,6,7] show an increase in GCT in the presence of fatigue, potentially due to a reduction in muscle stiffness or LSS [6,9,10]. Concerning VO, a decrease has been noted [7], with some authors [11] suggesting that this reduction may result from diminishing strength capacity of the main muscles in the lower extremities. As a strategy to enhance running economy, Moore [12] proposed that reducing GCT while maintaining stride frequency could lead to greater LSS, larger stride angles, and shorter swing times, thereby optimizing running technique.

The analysis of biomechanical parameters in half-marathon and marathon races is particularly relevant—for example, studies on predictive variables of half-marathon performance for male runners [13], the comparison of half-marathon runners according to their performance level [14], and the concurrent evolution of biomechanical and physiological parameters with acute fatigue induced by running [2]. In fatigued states, trained runners have been shown to reduce their stride frequency compared to a non-fatigued state [4,6,8], likely due to the muscle's reduced force generation capacity [4]. Conversely, other studies [11,15,16] found increases in stride frequency, with Matta et al. [7] and Morin et al. [11] observing no significant differences.

With the emergence of portable and low-cost equipment that allows data collection in field sessions, training, and competitions, alternatives are offered over older methods that require well-equipped research laboratories [17]. In this way, information more applicable to current sports practice is discovered as researchers can move participants to more sport-specific environments [18]. This alternative highlights the potential of these devices for gait analysis but without the corresponding limitations of traditional laboratory technology [19]. For assessing spatiotemporal parameters, the Stryd Running Power Meter has been widely studied in athletes to analyze the absolute reliability and concurrent validity of the Stryd system for the assessment of running stride kinematics at different velocities [20], as well as the agreement between spatiotemporal gait parameters from two different wearable devices and high-speed video analysis [21]. Additionally, the influence of biomechanical parameters on performance in elite triathletes has been analyzed [22].

Therefore, the main purpose of the present research is to analyze the stability of biomechanical parameters of the running stride of male trained athletes during a half-marathon competition, focusing on changes in SL, LSS, VO, and GCT. This approach offers new perspectives for optimizing the training of biomechanical parameters in running.

## 2. Materials and Methods

### 2.1. Participants

This study was conducted with eight trained male athletes who ran a half-marathon race spanning 21,097 m (race times 1:23:34 ± 00:10:12 h:m:s), all members of the same local training group. To be selected as trained athletes, participants were required to meet the following criteria [23]: (1) engagement in competition at the local level, (2) adherence to a regular training regime of more than three times per week, (3) specialization in the same sports specialty, and (4) a focus on training specifically for competitive events. The number of participants was determined through a statistical power analysis. Specifically, an a priori power calculation was conducted using G*Power 3.1 (Heinrich Heine Universität, Düsseldorf, Germany) [24] for the repeated measures ANOVA design with four measurements (representing the four race segments). Based on an effect size via eta squared of approximately 0.04 (estimated from a Cohen's $d$ of 0.2), an alpha level of 0.05, a desired power of 0.8, and an expected high correlation (>0.9) among the repeated biomechanical parameter measurements based on previous field measurements from the authors, the recommended total sample size was eight participants. While this sample size may be considered small, it is in line with similar studies in the field that have investigated biomechanical changes during endurance running events [25]. Prior to participation, all individuals read and provided written informed consent, acknowledging their understanding of the objectives of the study and the exclusively scientific application of the data collected, in alignment with the World Medical Association (WMA) Declaration of Helsinki; Ethical Principles for Medical Research Involving Human Subjects 1975 (revised in Fortaleza, Brazil in 2013). The ethical approval for this study was granted by the Ethics Committee of the University of Alicante (UA-2023-02-04). Table 1 presents the descriptive characteristics of the participants. The procedure for obtaining the descriptive data of the participants, obtained through the International Society for the Advancement of Kinanthropometry (ISAK) protocol, is shown below.

**Table 1.** Descriptive characteristics of the athletes.

| | Mean (M) | Standard Deviation (SD) |
|---|---|---|
| Age (years) | 38.8 | 5.4 |
| Body Mass (kg) | 70.2 | 4.7 |
| Body Height (m) | 1.77 | 0.05 |
| ∑ 8 skinfolds (mm) | 67.2 | 19.7 |
| Muscle Mass (kg) [26] | 22.6 | 11.8 |
| Fat Mass (kg) [27] | 6.86 | 2.03 |
| Fat Mass (%) [28] | 9.7 | 2.7 |

### 2.2. Procedure

A descriptive study was conducted through a field session, wherein all participants competed in the same official race under identical weather conditions and at the same time of day. To record biomechanical parameters, each athlete was equipped with the Stryd Summit Power Meter. This device was attached to the shoelace of the right foot and calibrated before the race started, following the manufacturer's guidelines. The field session, the "International Half-Marathon Villa de Santa Pola", was held on Sunday, 22 January 2023. This event is sanctioned by the Royal Spanish Athletics Federation and spans 21,097 m. The race features a total elevation change of 72 m, unfolding over a two-lap, urban circular route. Weather conditions on the day of the competition were optimal, with a temperature of 9 °C, relative humidity of 28%, wind speed of 3.5 m/s, and no precipitation (0.0 $l/m^2$).

For the analysis of biomechanical parameters and subsequent statistical analysis, the race was segmented as follows: Segment 1 data were collected from the race start to the first quarter (5274 m), Segment 2 data spanned from 5275 m to the midpoint (10,548 m), Segment 3 data covered from 10,549 m to the three-quarter mark (15,822 m), and Segment 4 data were gathered from 15,823 m to the race's conclusion.

### 2.3. Anthropometric Characteristics

The body composition of the athletes was estimated using precise anthropometric measurements, conducted between 48 and 72 h prior to the race at the Motion Analysis Laboratory of the University of Alicante (0001P1006). These measurements were performed by a Level 1 certified anthropometrist of the International Society for the Advancement of Kinanthropometry (ISAK). To ensure consistency and accuracy, the Ross and Marfell-Jones protocol [29] was adhered to, focusing on basic physical characteristics such as age, body mass, and height. For the measurements, a suite of approved equipment was employed, including a Holtain skinfold caliper, a Holtain bone breadth caliper (both from Holtain Ltd., Crymych, UK), scales and a stadiometer for height measurement, and an anthropometric tape (SECA Ltd., Hamburg, Germany) for circumferential measurements. Each participant underwent three repeated measurements for enhanced reliability, covering the biepicondylar humerus, bi-styloid, and biepicondylar femur breadths, as well as girths of the relaxed arm, flexed and tensed arm, waist, hip, and calf. Additionally, skinfold thickness was assessed at eight specific sites: triceps, subscapular, biceps, iliac crest, supraspinal, abdominal, thigh, and calf. The estimation of muscle mass was derived using the Lee equation [26], fat mass was calculated according to the Withers equation [27], and bone mass was determined using the Döbeln equation, modified by Rocha [28].

### 2.4. Biomechanical Parameters

The Stryd Summit Power Meter has been recognized as a reliable and valid instrument for the measurement of spatiotemporal biomechanical parameters during running [30], having been extensively utilized in research for this purpose [20–22]. The device, a carbon fiber-reinforced foot pod, is affixed to the toe cap of the right shoe. Weighing 9.1 g, it incorporates a 6-axis inertial measurement unit (IMU), comprising a 3-axis gyroscope and a 3-axis accelerometer [21]. This device enables the accurate capture of key biomechanical parameters, including GCT, LSS, VO, and SL. During the official competition, the device recorded the biomechanical parameters for each athlete across the entire race, which was divided into four race segments for analysis. The following spatial variables in the four race segments were analyzed through the Stryd "Power Center". This approach allowed for a detailed examination of how these parameters might vary within the context of race progression.

### 2.5. Statistical Analysis

Data are presented as the mean, standard deviation (SD), and 95% confidence interval (CI) for each race segment of the four parameters. The standard error (SE) and coefficient of variation (CV) were also calculated. Normality was checked through the Shapiro–Wilk test. A repeated measures ANOVA (within-subject factor: race segment) was used to test for any statistically significant differences in GCT, LSS, VO, and SL parameters across the different parts of the race. The effect size was computed using eta squared ($\eta^2$), with threshold values interpreted as small (0.01), medium (0.06), and large (0.14). To assess the consistency in the biomechanical parameters across the four race segments, the coefficient of variation (CV) was used, assessed as very good (<10%), good (10–20%), acceptable (20–30%), and not acceptable (>30%) [31]. In cases where statistical significance was found, Bonferroni post-hoc pairwise comparisons were computed to determine which specific segments differed from each other. Sphericity was checked using Mauchly's $W$ test, and the Greenhouse–Geisser $\varepsilon$ corrections were applied if sphericity was violated. All statistical analyses were performed using Jamovi version 2.3.28 (The Jamovi Project, 2022).

## 3. Results

Figure 1 shows a scattered plot connecting individual data points across the four race segments with lines. The different colors for the data points and lines represent different athletes from the sample. The lack of a clear trend in any of the four plots suggests that the measured variables (GCT, LSS, VO, SL) do not consistently increase or decrease throughout the segments of the race for the individuals.

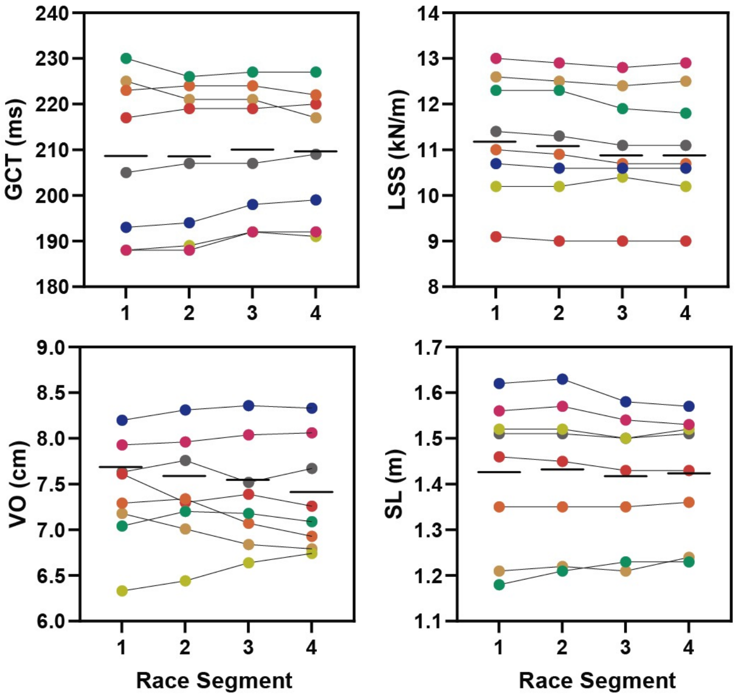


**Figure 1.** Individual variation in biomechanical parameters GCT, LSS, VO, and SL across four race segments. Each colored point represents a different athlete. Solid black lines indicate mean value of each parameter for each segment.

The descriptive statistics of four biomechanical parameters measured across all four race segments are shown in Table 2. The mean GCT is relatively stable, ranging narrowly from 208.5 to 210.0 ms; SD, which measures the spread of the data around the mean, decreases slightly across the segments, from 17.4 ms in the first segment to 14.1 ms in the last, suggesting less variability in GCT as the race progresses. The CV, which is the SD expressed as a percentage of the mean, also decreases, although within the threshold of very good consistency (CV < 10%). Regarding LSS, the mean value decreases slightly throughout the race from 11.28 to 11.10 kN/m, while SD and SE show minimal changes, suggesting consistent variability and precision across race segments, with good CV values for all segments. The mean VO is very stable, showing minimal fluctuation between 7.36 and 7.41 cm across the race segments, and the SD and SE are relatively constant, suggesting that the amount of spread and precision in measuring VO does not change much through the race. CV is also good for all race segments (CV < 10%). Finally, the mean SL shows negligible variation, with a slight decrease in the third segment before returning to the initial value in the last segment, while the SD decreases as the race goes on, suggesting SL becomes more consistent among the athletes for a measure of centimeters. The CV for all parameters remained relatively low and constant across all race segments, implying that the athletes maintained a steady and consistent pattern across the race. Overall, the results suggest that the absolute values for each of these variables do not change dramatically across the race segments.

**Table 2.** Comparison of biomechanical characteristics as within-subjects factors across four race segments: GCT, LSS, VO, and SL measurements.

| Factors | Race Segment | Mean | SD | 95% CI | SE | CV (%) |
|---|---|---|---|---|---|---|
| GCT (ms) | 1 | 208.6 | 17.4 | 194.1–223.1 | 6.14 | 8.3 |
| | 2 | 208.5 | 16.1 | 195.0–222.0 | 5.71 | 7.7 |
| | 3 | 210.0 | 14.6 | 197.8–222.2 | 5.15 | 6.9 |
| | 4 | 209.6 | 14.1 | 197.8–221.4 | 4.98 | 6.7 |
| LSS (kN/m) | 1 | 11.28 | 1.31 | 10.19–12.39 | 0.47 | 11.6 |
| | 2 | 11.21 | 1.31 | 10.11–12.31 | 0.47 | 11.7 |
| | 3 | 11.11 | 1.23 | 10.09–12.18 | 0.43 | 11.0 |
| | 4 | 11.10 | 1.28 | 10.04–12.16 | 0.44 | 11.5 |
| VO (cm) | 1 | 7.40 | 0.58 | 6.92–7.88 | 0.20 | 7.8 |
| | 2 | 7.41 | 0.58 | 6.92–7.90 | 0.21 | 7.9 |
| | 3 | 7.38 | 0.58 | 6.89–7.87 | 0.21 | 7.9 |
| | 4 | 7.36 | 0.59 | 6.86–7.86 | 0.21 | 8.1 |
| SL (m) | 1 | 1.42 | 0.17 | 1.29–1.56 | 0.06 | 11.4 |
| | 2 | 1.43 | 0.16 | 1.30–1.56 | 0.06 | 11.0 |
| | 3 | 1.41 | 0.14 | 1.30–1.54 | 0.05 | 9.9 |
| | 4 | 1.43 | 0.13 | 1.31–1.53 | 0.05 | 9.4 |

Table 3 presents the results of the RM ANOVA analyzing the differences across four race segments for four different measurements: GCT, LSS, VO, and SL. Mauchly's *W* test indicated that sphericity is violated for GCT, LSS, and SL ($p < 0.05$), and therefore the *df*, *MS*, and *p* values of the RM ANOVA are corrected with the $\varepsilon$ Greenhouse–Geisser correction. There were no significant effects of race segment on GCT ($F = 0.96$, $p = 0.38$), VO ($F = 0.23$, $p = 0.87$), and SL ($F = 1.07$, $p = 0.35$), all with a small effect size ($\eta^2$ 0.001 to 0.002). Regarding the LSS, the RM ANOVA result showed a significant effect of race segment ($F = 5.52$, $p = 0.03$) with a small effect size ($\eta^2 = 0.004$).

**Table 3.** Repeated measures (RM) ANOVA results for GCT, LSS, VO, and SL measurements.

| | Sphericity | | | RM ANOVA | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *W* | *p* | *ε* | *SS* | *df* | *MS* | *F* | *p* | $\eta^2$ |
| GCT | 0.13 | 0.04 | 0.46 | 13.12 | 1.37 [1] | 9.55 [1] | 0.96 | 0.38 [1] | 0.002 |
| LSS | 0.02 | <0.001 | 0.47 | 0.19 | 1.41 [1] | 0.13 [1] | 5.52 | 0.03 [1] | 0.004 |
| VO | 0.18 | 0.09 | 0.52 | 0.01 | 3 | 0.005 | 0.23 | 0.87 | 0.002 |
| SL | 0.08 | 0.01 | 0.45 | 0.0009 | 1.34 [1] | 0.007 [1] | 1.07 | 0.35 [1] | 0.001 |

[1] Greenhouse–Geisser corrected values as the sphericity assumption is violated.

The Bonferroni post hoc test reveals a statistically significant difference between the first and second race segments for LSS, with a mean difference of 0.07 kN/m and a *p*-value of 0.015. This indicates that the difference in LSS between these two segments is likely not due to random chance and is statistically significant after adjusting for multiple comparisons. The RM ANOVA analysis suggests that while most of the measurements did not significantly vary across race segments, LSS did show significant variability. However, the Bonferroni-corrected post hoc analysis specifies that this significant variability is only present between the first and second segments. The eta squared ($\eta^2$) values, which represent the effect size, are relatively small for all measures, indicating that even where significant effects are found, the proportion of variance explained by race segment differences is small.

## 4. Discussion

The primary aim of this study is to analyze the stability of the biomechanical parameters of the running stride among male trained athletes for endurance, specifically within the context of a half-marathon race.

Previous research has predominantly utilized laboratory settings to predict performance outcomes based on biomechanical analyses, employing various protocols [13,14]. In contrast, the investigation presented herein investigates the effects of fatigue on these parameters in the inherently dynamic and uncontrolled environment of an official half-marathon event. Findings are discussed with an emphasis on GCT, LSS, VO, and SL, delineating how fatigue alters these key performance indicators.

In the examination of GCT, no significant differences were found ($p$ = 0.38) and only small effect sizes were observed ($\eta^2$ = 0.002) among the four race segments. These non-significant differences are due to the similar values of the GCT during the four race segments (208.6 ± 17.4 ms, 208.5 ± 16.1 ms, 210.0 ± 14.6 ms, and 209.6 ± 14.1 ms, respectively). Considering that previous research [7] whose purpose was to investigate whether a slow start to the race affects performance and kinematic changes concluded that kinematic changes do not seem to be affected by race pace, this would explain the non-significant differences in a half-marathon, which is a long-distance race. Referring to the values of the stability of this parameter, prior research [7] has documented that GCT values for trained athletes might escalate from approximately 260 ms at the onset of a race to 300 ms in states of heightened fatigue. However, the average GCT values for athletes participating in this half-marathon were consistently below this range, across all segments of the race, suggesting a distinctive dynamic attributable to the specific duration and demands of the half-marathon. This notion finds further support when considering that short-distance triathletes have demonstrated remarkably consistent GCT values at different performance thresholds: 207.88 ± 1.37 ms at the first ventilatory threshold, 191.35 ± 2.94 ms at the second ventilatory threshold, and 176.33 ± 4.5 ms at maximum aerobic speed during incremental tests to exhaustion [22]. However, previous studies [2] that analyzed the influence of fatigue on biomechanics and physiological parameters based on running progression highlighted that the biomechanical parameters showed significant alterations, such as contact time and duty factor, even with a small change in perceived fatigue. In the same line, studies [6] that evaluated kinematic changes between km 8 and km 40 of a marathon in trained runners also identified increased contact time.

Regarding LSS, this parameter emerged as the singular metric showcasing statistically significant variations, notably between the initial two segments of the race ($p$ = 0.03), with a particular emphasis on the contrast observed between the first and second segments ($p$ = 0.015). Despite the statistical significance, the practical implications of these differences appear limited, given the small effect size noted across the cohort of eight athletes ($\eta^2$ = 0.004). A more granular examination of LSS values across the race's four segments (11.28 ± 1.31 kN/m for the first segment, 11.21 ± 1.31 kN/m for the second, 11.11 ± 1.23 kN/m for the third, and 11.10 ± 1.28 kN/m for the fourth) reveals a trivial decline as the race progresses, without statistical significance. However, although the changes in LSS between stages 1 and 2 were statistically significant, the absolute magnitude of this difference was very small (0.07 kN/m), and the effect size was also small ($\eta^2$ = 0.004), suggesting a limited practical impact. Looking at the broader picture across all four race stages, the overall decline in LSS is quite limited and may not necessarily be indicative of substantial muscular fatigue. The relatively stable values of LSS across the race segments could be interpreted as the athletes effectively managing and compensating for fatigue through their highly trained capabilities, resulting in minimal disruptions to this biomechanical parameter.

In the analysis of VO, this study did not reveal any statistically significant differences ($p$ = 0.87) with notably small effect sizes ($\eta^2$ = 0.002), indicating a stable trend across the evaluated metrics. These non-significant differences can be explained through previous research [9,10] that highlighted that, although VO can increase with fatigue, changes in this biomechanical parameter are minimal, and that this could lead to an increase in oxygen consumption. [11]

In the analysis focused on SL, comparative research involving trained ultramarathon runners over a duration of 6 h highlighted a decrease in SL from 1.30 m at the race's commencement to 1.10 m under conditions of fatigue [7]. Contrarily, the current study's investigation into half-marathon performance did not manifest significant differences ($p$ = 0.35), with effect sizes remaining minimal ($\eta^2$ = 0.001) across all race segments. Given that the subjects of both studies are trained runners, the observed disparity in SL alterations could potentially be attributed to the significantly shorter average competition time of the half-marathon 1:23:34 ± 00:10:12 (h:m:s) compared to the extended 6-h timeframe of the ultramarathon. This variance in race duration might offer insights into the findings from another study, which observed that half-marathon runners finishing between 80 and 90 min exhibit an SL of approximately 1.42 ± 0.09 m [14], closely aligning with the 1.43 ± 0.01 m SL measured for athletes in the current study. This parallel suggests that the race duration and intensity could significantly influence SL dynamics, emphasizing the need for further exploration into how different race conditions impact biomechanical parameters among endurance athletes.

This study acknowledges certain limitations that warrant mention and highlights avenues for forthcoming research directions. Firstly, the small sample size and the homogeneity of the participant pool, consisting solely of male athletes from a single training group, may limit the generalizability of the findings. Future studies could benefit from a larger, more diverse cohort to explore the biomechanical impacts of fatigue across different populations, including female athletes and those with varying levels of training and competitive experience. Additionally, while the naturalistic setting of an official half-marathon provides valuable insights into real-world performance, it also introduces uncontrollable variables that may affect the results, such as individual pacing strategies and environmental conditions. Subsequent research could aim to isolate these factors or examine their specific contributions to the observed biomechanical patterns. Moreover, the focus on a flat half-marathon course limits the applicability of the findings to races with different profiles, such as those with significant elevation changes. Investigating biomechanical parameters in varied race conditions would enhance our understanding of how terrain and course profile influence fatigue and performance. Finally, the incorporation of advanced biomechanical modeling and simulation techniques could offer deeper insights into the causal mechanisms underlying the observed changes in biomechanical parameters, further contributing to the optimization of training and performance strategies in endurance running.

## 5. Conclusions

The investigation into biomechanical parameters GCT, LSS, VO, and SL among trained male athletes during a flat half-marathon demonstrates minimal changes across these metrics. This finding stresses the importance of considering the athlete's proficiency level when interpreting sports science experiments, as these factors significantly influence biomechanical responses to endurance events.

Despite the availability of reference values for various running distances, speeds, and modalities, this study reinforces the notion that biomechanical performance is highly individualized. Athletes display distinct biomechanical adaptations tailored to their training levels and the specific demands of the competition, underscoring the need for personalized analysis in understanding and enhancing athletic performance. This insight calls for a nuanced approach to biomechanical research, focusing on individual rather than generic benchmarks.

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## References

1. Chen, T.L.; Wong, D.W.; Wang, Y.; Tan, Q.; Lam, W.; Zhang, M. Changes in segment coordination variability and the impacts of the lower limb across running mileages in half marathons: Implications for running injuries. *J. Sport Health Sci.* **2022**, *11*, 67–74. [CrossRef]
2. Prigent, G.; Apte, S.; Paraschiv-Ionescu, A.; Besson, C.; Gremeaux, V.; Aminian, K. Concurrent evolution of biomechanical and physiological parameters with running-induced acute fatigue. *Front. Physiol.* **2022**, *13*, 74. [CrossRef]
3. Knicker, A.J.; Renshaw, I.; Oldham, A.R.; Cairns, S.P. Interactive processes link the multiple symptoms of fatigue in sport competition. *Sports Med.* **2011**, *41*, 307–328. [CrossRef]
4. Hunter, I.; Smith, G.A. Preferred and optimal stride frequency, stiffness and economy: Changes with fatigue during a 1-h high-intensity run. *Eur. J. Appl. Physiol.* **2007**, *100*, 653–661. [CrossRef]
5. Derrick, T.R.; Dereu, D.; McLean, S.P. Impacts and kinematic adjustments during an exhaustive run. *Med. Sci. Sports Exerc.* **2002**, *34*, 998–1002. [CrossRef]
6. Chan-Roper, M.; Hunter, I.; Myrer, J.W.; Eggett, D.L.; Seeley, M.K. Kinematic changes during a marathon for fast and slow runners. *J. Sports Sci. Med.* **2012**, *11*, 77.
7. Matta, G.G.; Bossi, A.H.; Millet, G.Y.; Lima, P.; Lima, J.P.d.; Hopker, J.G. Influence of a slow-start on overall performance and running kinematics during 6-h ultramarathon races. *Eur. J. Sport Sci.* **2020**, *20*, 347–356. [CrossRef]
8. Reenalda, J.; Maartens, E.; Homan, L.; Buurke, J.J. Continuous three dimensional analysis of running mechanics during a marathon by means of inertial magnetic measurement units to objectify changes in running mechanics. *J. Biomech.* **2016**, *49*, 3362–3367. [CrossRef]
9. Fourchet, F.; Girard, O.; Kelly, L.; Horobeanu, C.; Millet, G.P. Changes in leg spring behaviour, plantar loading and foot mobility magnitude induced by an exhaustive treadmill run in adolescent middle-distance runners. *J. Sci. Med. Sport* **2015**, *18*, 199–203. [CrossRef]
10. Hayes, P.R.; Caplan, N. Leg stiffness decreases during a run to exhaustion at the speed at O 2max. *Eur. J. Sport Sci.* **2014**, *14*, 556–562. [CrossRef]

11. Morin, J.B.; Tomazin, K.; Edouard, P.; Millet, G.Y. Changes in running mechanics and spring–mass behavior induced by a mountain ultra-marathon race. *J. Biomech.* **2011**, *44*, 1104–1107. [CrossRef]
12. Moore, I.S. Is there an economical running technique? *A review of modifiable biomechanical factors affecting running economy. Sports Med.* **2016**, *46*, 793–807.
13. Gómez-Molina, J.; Ogueta-Alday, A.; Camara, J.; Stickley, C.; Rodríguez-Marroyo, J.A.; García-López, J. Predictive variables of half-marathon performance for male runners. *J. Sports Sci. Med.* **2017**, *16*, 187–194.
14. Ogueta-Alday, A.; Morante, J.C.; Gómez-Molina, J.; García-López, J. Similarities and differences among half-marathon runners according to their performance level. *PLoS ONE* **2018**, *13*, e0191688. [CrossRef]
15. Degache, F.; Morin, J.; Oehen, L.; Guex, K.; Giardini, G.; Schena, F.; Millet, G.Y.; Millet, G.P. Running mechanics during the world's most challenging mountain ultramarathon. *Int. J. Sports Physiol. Perform.* **2016**, *11*, 608–614. [CrossRef]
16. Zakaria, F.A.; El Badaoui, M.; Lamraoui, M.; Khalil, M. Fatigue study of ultra-runners: Presentation of a new approach for the separation of GRF signals components. *Mech. Syst. Signal Process.* **2016**, *75*, 648–667. [CrossRef]
17. Norris, M.; Anderson, R.; Kenny, I.C. Method analysis of accelerometers and gyroscopes in running gait: A systematic review. *Proc. Inst. Mech. Eng. Part P J. Sports Eng. Technol.* **2014**, *228*, 3–15. [CrossRef]
18. Higginson, B.K. Methods of running gait analysis. *Curr. Sports Med. Rep.* **2009**, *8*, 136–141. [CrossRef]
19. Lee, J.B.; Sutter, K.J.; Askew, C.D.; Burkett, B.J. Identifying symmetry in running gait using a single inertial sensor. *J. Sci. Med. Sport* **2010**, *13*, 559–563. [CrossRef] [PubMed]
20. García-Pinillos, F.; Roche-Seruendo, L.E.; Marcén-Cinca, N.; Marco-Contreras, L.A.; Latorre-Román, P.A. Absolute reliability and concurrent validity of the Stryd system for the assessment of running stride kinematics at different velocities. *J. Strength Cond. Res.* **2021**, *35*, 78–84. [CrossRef]
21. García-Pinillos, F.; Latorre-Román, P.Á.; Soto-Hermoso, V.M.; Párraga-Montilla, J.A.; Pantoja-Vallejo, A.; Ramírez-Campillo, R.; Roche-Seruendo, L.E. Agreement between the spatiotemporal gait parameters from two different wearable devices and high-speed video analysis. *PLoS ONE* **2019**, *14*, e0222872. [CrossRef]
22. Olaya-Cuartero, J.; Cejuela, R. Influence of biomechanical parameters on performance in elite triathletes along 29 weeks of training. *Appl. Sci.* **2021**, *11*, 1050. [CrossRef]
23. McKay, A.K.; Stellingwerff, T.; Smith, E.S.; Martin, D.T.; Mujika, I.; Goosey-Tolfrey, V.L.; Sheppard, J.; Burke, L.M. Defining training and performance caliber: A participant classification framework. *Int. J. Sports Physiol. Perform.* **2021**, *17*, 317–331. [CrossRef]
24. Faul, F.; Erdfelder, E.; Lang, A.; Buchner, A. G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behav. Res. Methods* **2007**, *39*, 175–191. [CrossRef]
25. Rabita, G.; Dorel, S.; Slawinski, J.; Sàez-de-Villarreal, E.; Couturier, A.; Samozino, P.; Morin, J. Sprint mechanics in world-class athletes: A new insight into the limits of human locomotion. *Scand. J. Med. Sci. Sports* **2015**, *25*, 583–594. [CrossRef]
26. Lee, R.C.; Wang, Z.; Heo, M.; Ross, R.; Janssen, I.; Heymsfield, S.B. Total-body skeletal muscle mass: Development and cross-validation of anthropometric prediction models. *Am. J. Clin. Nutr.* **2000**, *72*, 796–803. [CrossRef]
27. Withers, R.T.; Craig, N.P.; Bourdon, P.C.; Norton, K.I. Relative body fat and anthropometric prediction of body density of male athletes. *Eur. J. Appl. Physiol. Occup. Physiol.* **1987**, *56*, 191–200. [CrossRef]
28. Rocha, M. Bone weight of Brazilian men and women aged 17 to 25. *Arq. Anatomía Antropol.* **1975**, *1*, 445–451.
29. Ross, W.D.; Marfell-Jones, M.J. *Physiological Testing of the High-Performance Athlete*, 2nd ed.; MacDougall, J.D., Wenger, H.A., Green, H.J., Eds.; Canadian Association of Sports Sciences: Champaign, IL, Canada, 1991; pp. 223–308.
30. Olaya-Cuarte ro, J.; Cejuela, R. Contextualisation of running power: A systematic review. *J. Phys. Educ. Sport* **2020**, *20*, 2044–2051.
31. Scinicarelli, G.; Trofenik, M.; Froböse, I.; Wilke, C. The reliability of common functional performance tests within an experimental test battery for the lower extremities. *Sports* **2021**, *9*, 100. [CrossRef]