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Case Study on Posture Angle of Lower Extremity on Half Marathon Run Activity

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ABSTRACT

The half-marathon (HM) is a very popular endurance event with important physiological and biomechanical demands. This study compared lower extremity kinematics study during phase of the start, execution, and end of HM run. Hypothesis testing on significant differences is conducted across the race stages. One male subject aged 21 years was recruited, and three cameras GoPRO HERO12 Black were utilized to capture the movements of lower extremity and Quintic Biomechanics Software v33 was employed to extract angle at hip, knee and ankle joint throughout the half- marathon run activity. The angle data was taken during start (first lap), execution (26 laps) and finish (53 laps). The result shows that there is significant difference at the knee and ankle angles during start, execution and finish. Meanwhile there was no significant difference at the hip angle. The findings of the investigation have led to insights into improving performance and reducing the risk of injury in endurance running.

1. Introduction

Half-marathons are a 21.1-kilometers competition that have grown in popularity in recent years among people of all ages and genders throughout the world [1] . This expanding trend indicates an increased interest in long-distance running, with people of various backgrounds and fitness levels taking on the challenge of a half-marathon. Although the full marathon (FM) is the most popular endurance running distance, most runners compete in the half marathon (HM) [2]. Much research has looked at various elements of HM, including performance and participation trends, gender and age disparities, physiological correlations, and training; nonetheless, there is no clear cause of exercise-induced exhaustion [3-7]. This exhaustion results from prolonged physical exercise and affects a variety of physiological systems. A HM will have a significant impact on lower extremity.

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Biomechanics is one of the most important areas in understanding runners' performance and injury prevention, especially regarding the lower extremities [8]. Kinematics, which is the study of movement patterns, can provide insight into differences between high-performance and recreational runners [9]. Rodriguez [10] argue that such runners exhibit several biomechanical features, like higher vertical velocity of center of mass (CoM) at toe-off and larger flight times compared to recreational runners. This study supports the notion that precise mechanics of the lower limb are of great importance in the achievement of efficient running patterns. The study observed that high-performance runners-maintained stride length through prolonged aerial phases rather than by landing with a more extended knee, which is associated with increased vertical impulse during the stance phase [9].

The lower extremities, especially the shank and foot, play an important role in determining running efficiency and injury risk [11]. High-performance runners typically use a forefoot striking pattern, which brings the foot closer to the body during ground contact. This lowers the shank's inclination angle at initial contact, resulting in better alignment of the lower limb with the body's center of gravity [12,13]. According to Gomes [14], high-performance runners have an anterior shift in their center of pressure (CoP) relative to the ankle joint center at midstance. This increases ankle plantar flexor moments because it allows for more elastic energy storage in the achilleas tendon, which is then released later in stance to propel the runner forward.

The knee angle at initial contact is an important factor in determining running efficiency and injury risk [15-18]. Rhudy [19] noted that high-performance runners demonstrate greater knee flexion during the swing phase and at initial contact, enabling better shock absorption and efficient transfer of kinetic energy. These findings align with [20,21] who reported increased hip and knee flexion in competitive runners compared to recreational ones. Such adaptations reduce the risk of overuse injuries by distributing impact forces more evenly across the lower extremities [22,23]. In addition, foot strike patterns vary significantly between groups, with high-performance runners predominantly exhibiting forefoot strikes and recreational runners relying on rearfoot strikes. This would have implications for ground reaction forces, joint loading, and overall kinematic efficiency [24,25].

Our study was designed to examine the angle data of lower extremity on sagittal planes while starting, execution and finish half marathon run activity. By analyzing how running technique evolves over the course of a run, the research aims to identify significant differences of lower extremity joints. This is crucial for optimizing performance and reducing the risk of injury, as prolonged physical exertion can significantly impact running mechanics and efficiency [26]. The study's findings are expected to provide valuable insights for athletes, coaches, and healthcare professionals, enabling them to develop strategies that enhance performance, manage energy levels more effectively, and minimize injury risks in endurance sports.

2. Methodology

2.1 Experimental and Data Collection

The subject, are 21-year-old male, had a height of 1.67 m and a weight of 55.92 kg. The experiment was conducted at track and field, National Defence University of Malaysia (NDUM). The subject have been informed of the procedure of the study and the risks that could happen during HM run before they sign the consent form as an agreement to participate. The movement of the subject during HM was recorded using three GoPRO HERO12 Black cameras, capturing footage at 60 frames per second in 5300-pixel resolution. Each camera was mounted on a tripod, enabling precise adjustments to distance and height relative to the target area. The use of tripods ensured stable positioning, allowing the cameras to be accurately aligned for optimal recording. Figure 1 shows the top view of each camera's position. Camera 1 was set to capture while subject HM start, meanwhile camera 2 at execution HM and camera 3 at finish HM.

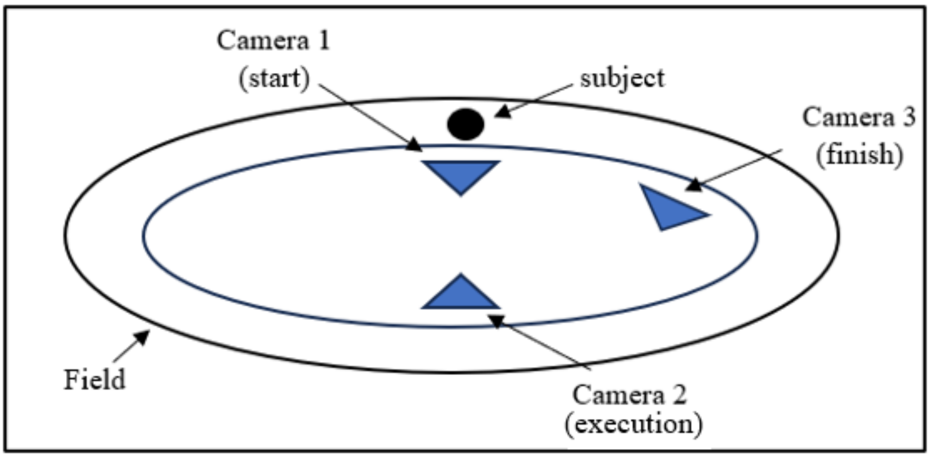

Fig. 1. Position of cameras and subject from the top view

Quintic Biomechanics v33 is a cutting-edge video analysis software that was used to digitize the angle data: hip, knee and ankle. The software supports frame-by-frame playback, digitization of key anatomical landmarks, and automatic calculation of kinematic variables such as joint angles and angular velocities. This makes it particularly valuable for analyzing the kinematics of the lower extremities, including the hip, knee, and ankle joints. Figure 2 represents the sagittal plane on left side lower extremity of the subject during HM activity while Figure 3 shows the process of digitization using Quintic Biomechanics v33 to extract the angle of hip, knee and ankle. Friedman test has been chosen to analyze the angle of lower extremity of HM activity on start, execution and finish. The results indicate a significant difference in hip, knee, and ankle angles during the start, execution, and finish phases when $p \leq 0.05$. Conversely, if $p \geq 0.05$, no significant differences are observed in these joint angles across the three phases.

Fig. 2. Position of the subject on a sagittal plane

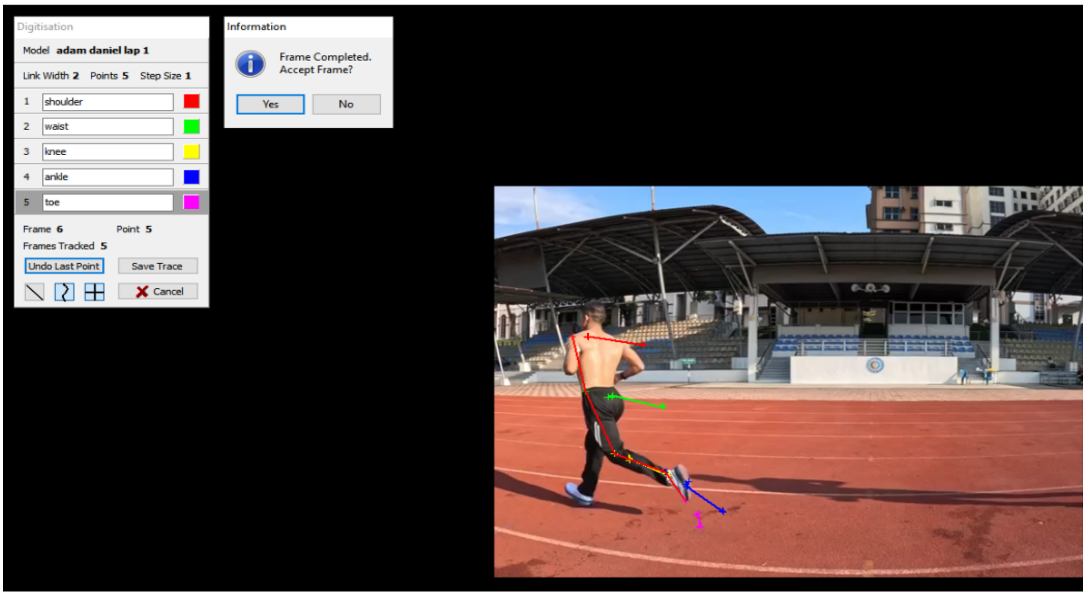

Fig. 3. Digitizing process using Quintic Biomechanics v33

3. Results and Discussion

Table 1 shows the mean, standard deviation, maximum and minimum hip, knee and ankle joint angles during the HM activity while start, execution and finish phase. According to Table 1, the value on hip angle while start, execution and finish are coherent compared to knee and ankle joint. The statistical test by Friedman test also showed there are significant differences of angle knee and ankle while start, execution and finish with ($p \leq 0.05$). Meanwhile for the hip angle there was no significant difference ($p \geq 0.05$). Figures 4,5 and 6 represent the graph of hip, knee and ankle while start, execution and finish for HM activity.

Table 1
The mean, maximum and minimum values of angle of hip, knee and ankle on start, execution and finish of HM activity

Variable	Mean $\pm$ SD	Max	Min	*p*-value
Start				
Hip flexion	164.88 $\pm$ 12.30	186.43	143.02	0.068
Knee flexion	122.09 $\pm$ 32.99	169.46	58.13	0.0002
Ankle flexion	71.91 $\pm$ 19.36	113.26	34.54	1.2×10^{-4}
Execution				
Hip flexion	161.91 $\pm$ 8.04	178.87	149.21	0.345
Knee flexion	123.56 $\pm$ 26.76	159.23	73.07	0.0032
Ankle flexion	85.98 $\pm$ 19.23	121.94	47.19	0.4×10^{-3}
Finish				
Hip flexion	164.38 $\pm$ 11.47	183.47	145.42	0.451
Knee flexion	127.47 $\pm$ 25.70	163.79	64.62	0.6×10^{-5}
Ankle flexion	79.26 $\pm$ 16.59	117.88	50.73	0.24×10^{-6}

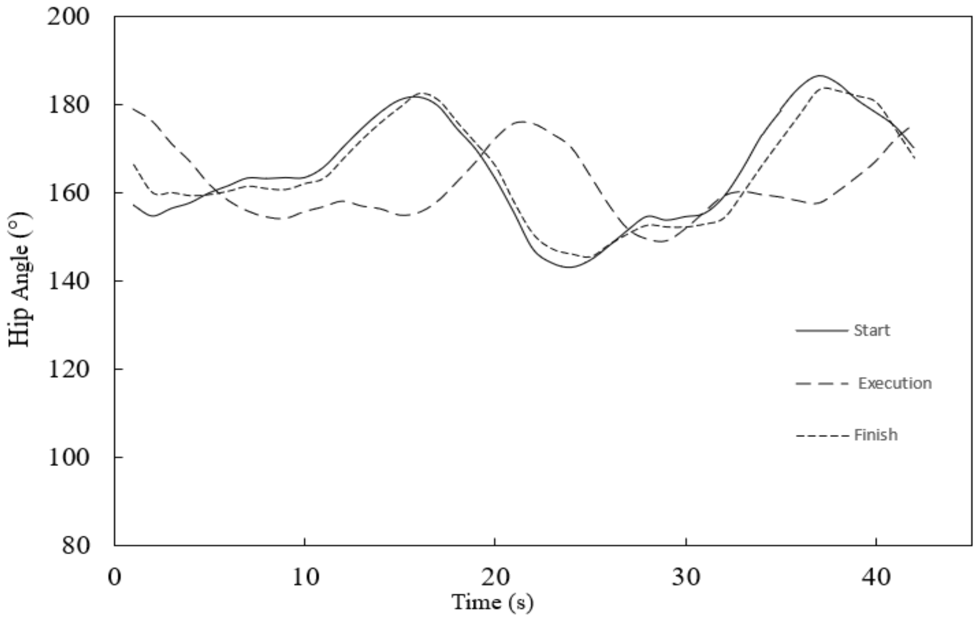

Fig. 4. Hip angle while start, execution and finish

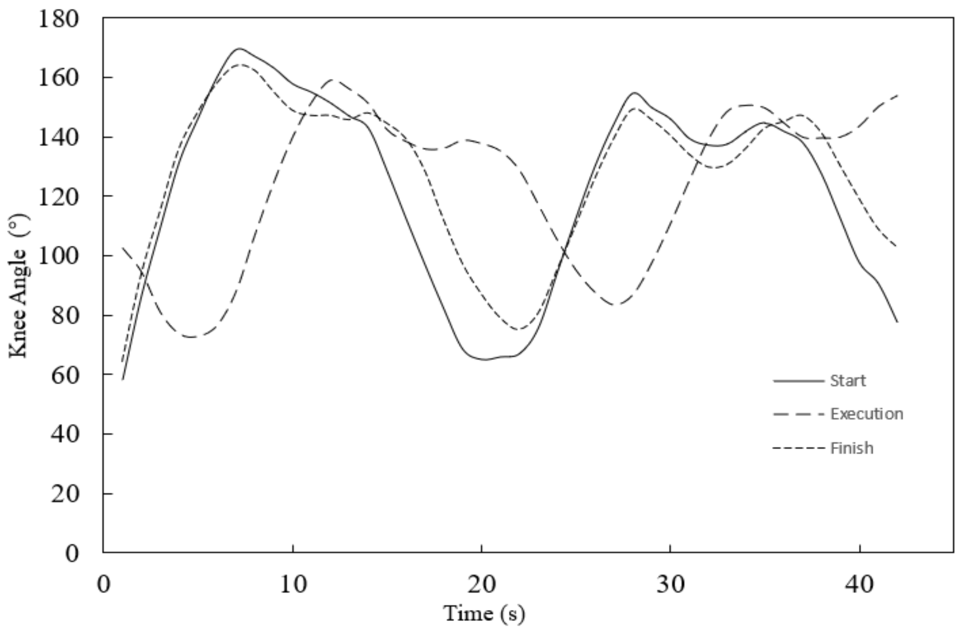

Fig. 5. Knee angle while start, execution and finish

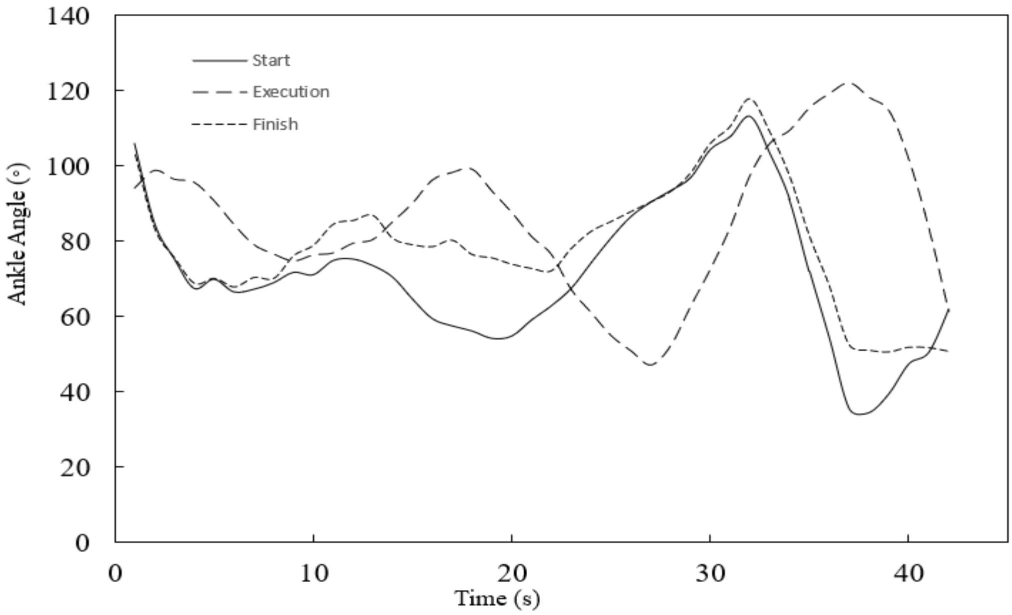

Fig. 6. Ankle angle while start, execution and finish

The biomechanics of the lower extremity are critical for understanding human movement, particularly in activities like half-marathon (HM) running. Analyzing joint angles such as the hip, knee, and ankle provides insights into performance, stability, and injury risk. In this study, the movements of one subject were evaluated across three phases: the start, execution, and finish of the HM run.

The hip angle varied throughout the run. Based on Figure 4, it measured 157.16° in the first frame of the start phase, gradually decreasing to 143.02° by frame 24, then peaking at 186.43° in frame 37. This indicates that participants began with flexion and then moved into an extended posture. According to [22] that significant fluctuations in hip angle can hinder forward propulsion and reduce running efficiency. The hip angle measurements during both the execution and finish phases closely resembled those in the start phase. Runners who maintain a stable hip angle during the finish phase tend to experience lower fatigue and sustain better propulsion [20].

Regarding knee angles, Figure 5 shows that the start phase started at 58.13°, rose to 169.46° at frame 8, and then fell to 65.89° at frame 21. This pattern suggests overstriding, where initial excessive knee flexion is followed by extension around frame 18. Xu *et al.*, [24] observed that overstriding elevates impact forces on the knee joint, increasing the risk of injuries like patellar tendinitis. In the execution phase, the knee angle began at 102.72°, dropped to 73.86° by frame 6, then rose to 159.23° by frame 13 again indicating overstriding, with knee flexion followed by extension near frame 10. Excessive knee flexion can strain the quadriceps and impair performance efficiency [27]. In the finish phase, the knee angle started at 64.62°, peaked at 163.79° by frame 8, and decreased to 75.38° by frame 23. This trend reflects overstriding as well, with early flexion and later extension near frame 20 [25]. Richards highlighted that overstriding in the final phase increases stress on the lower limbs, elevating the risk of fatigue-related injuries.

Ankle position: inversion or eversion is one of the major biomechanical stresses placed on the ankle during a HM. Running surface, foot striking pattern, and weariness are some of the variables that can affect this. Performance can be maximized and injury risk reduced with proper technique, appropriate footwear, and attention to potential weaknesses [28]. Based on Figure 6, the ankle angle started at 73.96° in the first frame of the start phase and rose to 113.38° by frame 17, indicating plantar flexion, which may lead to greater vertical impact [8]. According to Zhuang [8] warned that excessive plantar flexion reduces force absorption efficiency, raising the risk of Achilles tendon injuries. In the execution phase, the ankle angle began at 85.93° and increased to 105.25° by frame 17, again showing plantar flexion and potential for higher vertical impact [12]. During the finish phase, the ankle angle started at 76.96° and increased to 112.03° by frame 7, showing the same pattern. Whitacre [12] concluded that excessive plantar flexion near the end of a run reduces force application efficiency and can compromise sprint performance.

The biomechanical analysis of the lower extremities joint angles revealed that, whereas hip and knee mechanics were stable throughout the race, the ankle joint fluctuated significantly, notably during the propulsion phase. The subject ankle angle peaked at 145.46° before dropping to 94.4° near the end of the race, highlighting its importance in propulsion and vulnerability to fatigue-related changes. This observation is consistent with research indicating that running-induced tiredness modifies joint kinematics, notably at the ankle, resulting in alterations in stride mechanics and propulsion efficiency. As tiredness advances, runners' plantar flexion at push-off decreases, which can impair performance and increase the risk of overuse injuries [29].

4. Conclusions

This study has analyses the angle data at left side of lower extremity on HM activity based on three phases: start, execution and finish. The biomechanical analysis of the lower extremities joint angles revealed that, whereas hip mechanics were stable throughout the race, the knee and ankle joint fluctuated significantly, notably during the propulsion movement. This observation is consistent with current research that indicating that running-induced tiredness modifies joint kinematics, notably at the ankle, resulting in alterations in stride mechanics and propulsion efficiency. As tiredness advances, runners' plantar flexion at push-off decreases, which can impair performance and increase the risk of overuse injuries. According to the study's findings, athletes, coaches, and medical experts will be able to create techniques that improve performance, better energy levels, and reduce the risk of injury in endurance sports. The limitations of this study include the collection of data from a single individual, which constrains the generalizability of the findings. The results may not fully represent variations that could occur across individuals with different physical characteristics, skill levels, or movement patterns. Future research should incorporate a larger and more diverse sample size to capture inter-individual variability and strengthen the reliability and applicability of the findings. Additionally, including participants from various age groups, genders, and experience levels could provide a more comprehensive understanding of the biomechanical patterns observed.

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Conflict of Interest Statement
The authors declare that there is no conflict of interest regarding the publication of this paper.

Author Contributions Statement
Syazwana Aziz: Conceptualization, methodology, writing-original draft. Batrisya Nasuha Mohd Nor Hadi: Experimental, collecting data, writing draft. Faizal bin Abdul Manaf: Methodology, writing-review and editing. Nur Athirah binti Abd Rahman: Experimental, writing-review & editing.

Normurniyati Abd Shattar: Writing-review and editing, visualization. All authors discussed the results and contributed to the final manuscript.

Data Availability Statement

All data generated or analyzed during this study are included in this published article. Additional datasets are available from the corresponding author upon reasonable request. Where applicable, publicly available datasets used in the study are cited in the references

Ethics Statement

This study was conducted in accordance with the ethical standards of the institutional and/or national research committee. Ethical approval was obtained where required, and informed consent was obtained from all participants involved in the research.

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