

# Effect of target-distance training in terms of centrifugal force on some biomechanical variables and 400m hurdles performance under 20 years old

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## Abstract

The policy to reduce physical education classes from two to one hour per week in Wasit Province, Iraq, coupled with weak administrative support from school principals, poses a serious challenge for physical education teachers. However, there is currently no empirical evidence examining the role of school principals in facilitating physical education instruction following this policy. This study aims to uncover the reality of the principal's role, identify differences in perceptions based on school accreditation, analyze the relationship between teachers' years of service and their perceptions of support, and identify the dominant barriers faced by teachers. The study employs a quantitative approach using a descriptive-analytical and comparative-correlational survey design. A purposive sample of 115 physical education teachers from the city center of Kut, Wasit, was selected. The instrument consisted of a 5-point Likert scale questionnaire with content validity (CVI = 0.88) and reliability (Cronbach's alpha = 0.91). Data analysis utilized descriptive statistics, independent t-tests, and Pearson's correlation. The role of the principal was classified as low (mean = 2.33). There was a significant difference in perceptions between A-accredited and non-A-accredited schools ( $t = 2.87$ ;  $p = 0.005$ ). A moderate negative correlation was found between years of service and perceived support ( $r = -0.342$ ;  $p < 0.001$ ). The dominant barriers were: lack of external cooperation (1.72), lack of funding (1.76), and the use of physical education time for other activities (3.29). These findings are linked to transformational leadership theory and occupational socialization theory. School principals fell short on all four dimensions of transformational leadership. Senior teachers have more negative perceptions due to accumulated experience and burnout. Principal support for physical education at Wasit is very low. A policy review, minimum budget allocation, principal training, and revision of accreditation instruments are needed.

**Keywords:** Principals; physical education activities; physical education teachers; accreditation

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## Introduction

Running events, particularly short-distance running events in track and field, are significantly influenced by various factors, requirements, and conditions inherent to the event (Bompa & Haff, 2009; Schmidt & Wrisberg, 2008). This has prompted many researchers and specialists in this field to explore new topics through research, studies, and experiments utilizing the latest advancements in sports science (Komi, 2003). Precise artistic and scientific aspects are an integral part of the framework of a running event (Hay, 1993). The 400-meter hurdles is an event that relies on high-precision technique when clearing the hurdles and the ability to maintain specific physical capabilities throughout the race.

The aim is to maintain the same rhythm throughout the entire track without causing a noticeable decrease in stride length and frequency, and generally to maintain running stride performance speed both between the hurdles and while clearing them. The most important factors influencing race time are the extent to which the kinematic rhythm of performance is maintained throughout the race (Hunter et al., 2005; Susanka & Stepanek, 1980), as well as the external forces affecting the runner's trajectory (Hall, 2018; Enoka, 2015). One such force is centrifugal force, which is an external force that impedes the runner's path due to the nature of the curve's shape (Usherwood & Wilson, 2005).

Runners attempt to counteract this force which pulls them outward by tilting their bodies inward, thereby causing changes and effects on most biomechanical indicators of running between the gates and while passing through them (Leary & White, 2013). The significance of this research lies in considering the laws of centrifugal force when designing specific training for turns by balancing training intensity according to each runner's mass and accounting for the turn's radius and linear speed during the turn (Winter, 2009; Robertson et al., 2013).

Modern methods and tools aligned with the laws of physics are utilized in developing various biomechanical indicators that lead to performance enhancement (McGinnis, 2013). Based on this, these exercises can serve as a scientific solution contributing to improved athletic performance in the 400m hurdles race. Although various studies have explored the biomechanics of the 400m hurdles (Mero & Komi, 1985; Salo et al., 2011), no study has specifically designed centrifugal force-based training on curved tracks while simultaneously considering mass, linear velocity, and track radius in adolescent athletes (age < 20 years).

Training specifically on partial-distance intervals provides both numerical and performance benchmarks for the 400-meter hurdles. This is what we observed in the training of world champions (IAAF, 2015), and this is what we did not find in the training of local runners, where runners are not trained to control the physical variables that specifically affect split times. Local runners tend to treat curves the same as straight tracks in training stress situations, even though curves are very different from straight tracks, as external forces have a greater influence on curves (Chang & Kram, 2007; Churchill et al., 2015).

This is what we observed regarding centrifugal force. Additionally, the body's movement path and the positions of body parts differ in turns compared to straight sections (Hamill & Knutzen, 2009; Novacheck, 1998). Therefore, this study aims to identify the values of several biomechanical variables at the target distance; design exercises targeting these biomechanical variables at the target distance; test the effects of target-distance centrifugal force training on

several biomechanical variables at the target distance and 400m hurdle running performance. The statistical hypothesis tested is H0: there is no significant difference between the pre-test and post-test versus H1: there is a significant difference at  $\alpha=0.05$  (Field, 2018; Vincent & Weir, 2012).

## Methods

This study employed an experimental method using a single-group pretest-posttest design. This design was chosen because it aligns with the research objectives and research questions, namely to examine the effects of centrifugal-style training on biomechanical variables and 400-meter hurdle performance. The experimental design diagram used is as follows: the pre-test was conducted on July 1, 2025, followed by an intervention consisting of 24 sessions over 9 weeks, and concluded with a post-test from September 2 to 6, 2025. During the pre-test phase, biomechanical measurements and 400m hurdle running performance were assessed; during the intervention phase, centrifugal force-based training was administered using the formula  $F = m \cdot v^2/r$ ; and during the post-test phase, the same measurements were taken using identical methods.

The study population consisted of all 400-meter hurdlers at the National Sports Talent Development Center in Baghdad Province, totaling six runners in the under-20 youth category. The sample was selected using purposive sampling, representing 100% of the study population. Prior to the study, approval was obtained from the Wasit University Research Ethics Committee under Number 234/FPESS/2025. All participants and their parents or guardians signed informed consent forms after receiving an explanation of the study's objectives, procedures, risks, and benefits. Table 1 presents the descriptive statistics of the demographic variables in the study sample.

Based on the table, the average body mass of the sample is 62.133 kg with a standard deviation of 3.060, a median of 62, and a skewness coefficient of 0.047, indicating that the data distribution is close to normal. The average height of the sample is 175.966 cm with a standard deviation of 3.600, a median of 177, and a skewness coefficient of -0.318. The mean chronological age of the sample is 18.943 years with a standard deviation of 0.816, a median of 18.500, and a kurtosis coefficient of -0.857. The average training duration of the sample was 21.276 months with a standard deviation of 3.710, a median of 21.500, and a torsion coefficient of -0.196. Torsion coefficient values between -2 and +2 indicate that the data for these four variables are normally distributed.

Table 1. Descriptive statistics of the independent variables in the sample

Variables	Mean	Std. Deviasi	Median	Standard Error	Torsion Coefficient	Standard Torque Error
Mass (kg)	62,133	3,060	62	1,249	0,047	0,845
Height (cm)	175,966	3,600	177	1,470	-0,318	0,845
Chronological age (years)	18,943	0,816	18,500	0,333	-0,857	0,845
Training age (months)	21,276	3,710	21,500	1,514	-0,196	0,845

Based on a literature review and related studies in the fields of biomechanics and athletics, the biomechanical variables identified for this study include centrifugal force, average distance before passing the hurdle, average distance after passing the hurdle, hurdle stride smoothness index, and biomechanical kinetic rhythm. Centrifugal force is defined as the force that causes centripetal acceleration in an object moving in a circle, measured by taking a distance of 5 meters from the apex of the second turn and calculating the average speed, then applying the law of centrifugal force  $F = m \cdot v^2 / r$ , where  $F$  is the centrifugal force in Newtons,  $m$  is the runner's mass in kilograms,  $v$  is the linear velocity in meters per second, and  $r$  is the curve radius in meters.

The distance before the goal is measured directly via video analysis as the distance between the rear foot's contact point and the goal. The distance after the goal is also measured via video analysis as the distance between the goal and the front foot's contact point. The smoothness index is calculated by determining the momentum from the moment of rear foot contact until the vertical position of the goal step and from the vertical position until the moment of the last foot contact, using the kinetic flow formula, which is equal to the second momentum minus the first momentum. The biomechanical kinetic rhythm is calculated using the formula ground contact time divided by flight time minus one, where ground contact time is the time from when the foot touches the ground until it leaves the ground, while flight time is the time from when the foot takes off until it touches the ground again.

Prior to the pre-test, intra-rater and inter-rater reliability tests were conducted on 5 sample recordings at one-week intervals. The reliability test results showed that the intraclass correlation coefficient (ICC) for the distance before the goal was 0.92, for the distance after the goal was 0.89, and for the fluidity index was 0.90 with a significance level of  $p < 0.01$ . These values indicate excellent reliability. For motion recording, a high-speed camera with the following specifications was used: GoPro Hero 11 Black, frame rate 240 fps, resolution 1080p (1920 x 1080 pixels), shutter speed 1/1000 second, and spatial calibration using 1-meter markers within the field of view.

Other equipment used included 10 IAAF-standard hurdles, 8 high-speed cameras, a digital stopwatch with an accuracy of 0.01 seconds, tripods, and Kinovea motion analysis software version 0.9.5. The 400m hurdle race performance test procedure was conducted in accordance with the 2019 IAAF international regulations. Video recording was performed by placing high-speed cameras at the hurdles inside the curve, perpendicular to each hurdle, so as to cover a distance of 3 meters before and after the hurdles. The distance between the camera and the hurdles was set at 8.5 meters, and the focal height was set at 110 cm. The researchers conducted a preliminary experiment on June 21, 2025, at the Ministry of Youth and Sports Athletics Stadium in Baghdad.

The objectives of this preliminary experiment were to verify the validity of the high-speed camera, determine the camera dimensions and focal height, assess the adequacy of support staff, verify the validity of specific training exercises, and determine the time required to capture video from a distance of 5 meters from the apex of each turn. The pre-test was conducted on July 1, 2025, at 4:00 PM with the assistance of support staff. The test included a 400m hurdle running performance test on the Ministry of Youth and Sports' athletic track in Baghdad, as well as video recording to measure biomechanical indicators for each hurdle

within the curve. Based on a literature review and the researcher’s personal experience, as well as consultations with several experts in the fields of sports training and athletics, 18 specialized exercises were designed in accordance with the law of centrifugal force.

These exercises were divided into 3 units and distributed over a 2-month training period. The specialized exercises were implemented based on the centrifugal force law  $F = m \cdot v^2/r$ , carried out as the core component of the training units during the specific preparation and pre-competition periods, in coordination with the sample’s coaches. Table 2 presents examples of the exercises provided to the research sample.

Table 2. Examples of centrifugal force-based exercises

Exercise Code	Exercise Description	Turn Radius	Additional Weight
T1	Run 100 m from a flying start on a 32-meter-radius curve with a weighted belt on the right leg	32 m	2% of the right leg's mass
T2	Run 100 m from a flying start on a 33-meter-radius curve	33 m	No weight
T3	Run 60 m from a flying start on a 32-meter-radius curve with hurdles 0.91 m high	32 m	No weight
T4	Run 50 m from a seated position on a 30 m radius curve with hurdles 0.91 m high	30 m	No weight
T5	Run 100 m from a seated position on the first track with 6 hurdles 0.91 m high	First Lap	No weight
T6	Run from a flying start on a 30 m radius curve with an additional weight on the right leg	30 m	2% of the right leg's mass
T7	Run from a flying start over two curves and one straight track with 3 hurdles on the first curve and 6 hurdles on the second curve	Varies	No weight
T8	Run from a flying start over two curves and one straight track on a 33 m radius curve	33 m	No weight

As shown in Table 2, exercises T1 and T6 used an additional load of 2% of the right leg’s mass to increase the specific muscle load during cornering. Exercises T2 and T8 used a larger curve radius (33 m) for intensity variation, while exercises T3 and T4 used a smaller radius (30–32 m) with additional hurdles to simulate actual race conditions. Exercises T5 and T7 combined several hurdles in a single training sequence to develop coordination and specific endurance. The total number of training units applied to the study sample reached 24 training units distributed over 9 weeks at a frequency of 3 units per week.

The first training unit began on July 2, 2025, and the final training unit ended on August 31, 2025. Training sessions were held on Saturdays, Tuesdays, and Thursdays. The researchers adopted high-intensity interval training and repetitive training methods in designing the training load, using a 3-1 undulation principle over the course of a week, which was considered most suitable for developing the indicators and abilities under study. All training sessions designed by the researchers fall within a training curve of high, maximal, and submaximal intensity, and are based on the centrifugal force factor  $m \cdot v^2/r$ . After completing all training units, the researchers conducted post-tests on Monday, Tuesday, and Friday, September 2, 3, and 6, 2025, respectively.

The researchers ensured that the same procedures as in the pre-test were followed, with identical conditions regarding time, location, method, and test administration. The collected data were analyzed using Statistical Package for Social Sciences (SPSS) version 26.0. The

statistical procedures used included descriptive statistics (mean, standard deviation, median, standard error), the Shapiro-Wilk normality test to verify data distribution, a paired t-test to compare the pre-test and post-test, and Cohen's d to calculate the effect size. The significance level was set at  $\alpha = 0.05$ . The criteria for interpreting Cohen's d followed the guidelines that  $d = 0.20$  indicates a small effect,  $d = 0.50$  indicates a moderate effect, and  $d = 0.80$  indicates a large effect.

## Results

Penelitian ini bertujuan untuk menguji pengaruh latihan berbasis gaya sentrifugal terhadap beberapa variabel biomekanika dan performa lari 400m gawang pada 6 orang pelari remaja di bawah usia 20 tahun. Data yang terkumpul dianalisis menggunakan statistik deskriptif dan uji-t berpasangan (paired sample t-test) dengan tingkat signifikansi  $\alpha = 0,05$ . Selain itu, untuk mengukur besarnya pengaruh latihan, dihitung pula nilai Cohen's d sebagai ukuran efek (effect size). Seluruh data dalam bagian ini disajikan untuk tikungan pertama dan kedua, namun pembahasan difokuskan pada tikungan pertama karena tikungan tersebut merupakan lokasi dengan paparan gaya sentrifugal tertinggi.

Table 3 presents the mean and standard deviation of several biomechanical indicators measured through kinematic analysis during the pre-test and post-test for the first turn. Based on the table, for the centrifugal force variable, the pre-test mean was 103.108 with a standard deviation of 11.555, while the post-test mean increased to 105.168 with a standard deviation of 9.80. For the average distance before passing the goalpost variable, the pre-test mean was 1.801 m with a standard deviation of 0.1132, increasing to 1.841 m with a standard deviation of 0.086 in the post-test. For the variable of average distance after passing the goal, the pre-test mean was 1.196 m with a standard deviation of 0.019, decreasing to 1.170 m with a standard deviation of 0.030 on the post-test.

This decrease in value indicates improvement, as a shorter distance after the hurdle indicates better stability and speed. For the biomechanical kinetic rhythm variable of the hurdle-jumping step, the pre-test mean value was -0.597 with a standard deviation of 0.0431, changing to -0.589 with a standard deviation of 0.032 in the post-test. Values approaching -0.5 to -0.6 indicate a balance between ground contact time and flight time, and a shift toward -0.5 indicates an improvement in rhythm. For the step smoothness index variable, the pre-test mean was -12.859 with a standard deviation of 4.676, increasing to -10.448 with a standard deviation of 3.098 in the post-test. Smaller values (closer to zero) indicate smoother movement.

Table 3. Mean values and standard deviations of several biomechanical indicators in the pre-test and post-test (first turn)

Variables	Pre-test	Post-test	Mean	Std. Deviasi
	Mean	Std. Deviasi		
Centrifugal force	103,108	11,555	105,168	9,80
Average distance before crossing the hurdle (m)	1,801	0,1132	1,841	0,086
Average distance after crossing the hurdle (m)	1,196	0,019	1,170	0,030
Biomechanical kinetic rhythm of the hurdle stride	-0,597	0,0431	-0,589	0,032
Hurdle stride fluidity index	-12,859	4,676	-10,448	3,098

Table 4 presents the results of the comparison between the pre-test and post-test, including the mean difference, standard deviation of the difference (SDD), calculated t-value, significance level (p-value), and Cohen’s d effect size. Based on the table, for the centrifugal force variable at the first turn, the mean difference was 2.059 with a standard deviation of the difference of 3.580, a calculated t-value of 1.409, and a significance value of  $p = 0.218$ . Since the p-value is  $> 0.05$ , this difference is considered statistically insignificant. However, the Cohen’s d effect size for this variable is 0.58, which falls into the moderate effect category according to (Cohen’s, 1988) criteria.

This indicates that although statistically insignificant (likely due to the small sample size), the 2.0% increase in centrifugal force has practical significance in the context of athletic performance. For the variable of average distance before passing the goalpost at the first turn, an average difference of 0.040 was obtained with a standard deviation of 0.035, a calculated t-value of 2.739, and a significance value of  $p = 0.041$ . Since  $p < 0.05$ , this difference is considered statistically significant. The Cohen’s d effect size for this variable is 1.08, which falls into the large effect category, indicating that centrifugal-style training has a very strong influence on increasing stride length before the hurdle.

For the variable of average distance after passing the goalpost at the first turn, an average difference of -0.026 was obtained, with a standard deviation of 0.020, a calculated t-value of 3.162, and a significance level of  $p = 0.025$ . Since  $p < 0.05$ , this difference is considered statistically significant. The Cohen’s d effect size for this variable is 1.08, which also falls into the large effect category, indicating that the exercise is effective in shortening the distance after the hurdle, thereby improving stability and speed. For the variable of the biomechanical kinetic rhythm of the hurdle stride at the first turn, a mean difference of -0.007 was obtained with a standard deviation of the difference of 0.014, a calculated t-value of 1.333, and a significance value of  $p = 0.240$ .

Since the p-value is greater than 0.05, this difference is considered statistically insignificant. The Cohen’s d effect size for this variable is 0.22, which falls into the category of a small effect, indicating that the exercise has a limited impact on improving kinetic rhythm. For the variable of step fluency index at the first turn, a mean difference of -2.410 was obtained with a standard deviation of the difference of 2.955, a calculated t-value of 1.998, and a significance value of  $p = 0.102$ . Since the p-value is greater than 0.05, this difference is considered statistically insignificant. However, the Cohen’s d effect size for this variable is 0.58, which falls into the moderate effect category. An 18.7% increase in the smoothness index indicates a practically meaningful improvement, even though it has not yet reached statistical significance.

Table 4. Results of the pre-test and post-test difference test for biomechanical indicators (first turn)

Variables	MD	SDD	t hitung	p-value	Cohen's d	Impact Category	Significance
Centrifugal force	2,059	3,580	1,409	0,218	0,58	Moderate	Not significant
Distance before the goal (m)	0,040	0,035	2,739	0,041	1,08	High	Significant
Distance after the goal (m)	-0,026	0,020	3,162	0,025	1,08	High	Significant
Kinetic rhythm	-0,007	0,014	1,333	0,240	0,22	Low	Not significant
Smoothness index	-2,410	2,955	1,998	0,102	0,58	Moderate	Not significant

Notes: MD = mean difference; SDD = standard deviation of the difference; Cohen’s d is categorized according to Cohen (1988): small = 0.20; moderate = 0.50; large = 0.80.

Table 5 presents the results of the 400-meter hurdles performance, which is the main variable in the research title. Based on the table, the average pre-test time was 62.34 seconds with a standard deviation of 2.15, while the average post-test time was 60.12 seconds with a standard deviation of 1.98. Thus, there was a reduction in running time (performance improvement) of 2.22 seconds. The results of the paired t-test showed a calculated t-value of 3.451 with a significance level of  $p = 0.018$ . Since  $p < 0.05$ , this difference is considered statistically significant. The Cohen’s d effect size for this variable is 1.07, which falls into the large effect category, indicating that centrifugal-style training has a very strong influence on the overall improvement in 400m hurdle running performance.

Table 5. Results of the pre-test and post-test difference test for 400m hurdle running performance

Variable	Pre-test (mean ± SD)	Post-test (mean ± SD)	MD	t hitung	p-value	Cohen's d	Category: Effects
400m hurdles time (seconds)	62,34 ± 2,15	60,12 ± 1,98	-2,22	3,451	0,018*	1,07	Large

Notes: \* $p < 0.05$  (significant); MD = mean difference; SD = standard deviation

In summary, the results of this study indicate that the research hypothesis was partially accepted. The variables showing statistically significant differences with a large effect size were the distance before the hurdle, the distance after the hurdle, and the 400-meter hurdle run time. Meanwhile, the centrifugal force and fluidity index variables showed a moderate effect but were not statistically significant, likely due to the small sample size ( $n=6$ ). Post-hoc analysis indicates that to achieve a statistical power of 0.80 with a moderate effect ( $d=0.50$ ), a minimum sample size of 18 participants is required. The kinetic rhythm variable showed a small and non-significant effect, thus requiring a longer intervention or a more sensitive measurement method.

## Discussion

The discussion of these research results aims to interpret both significant and non-significant statistical findings and relate them to relevant theories in biomechanics and exercise physiology. The results indicate that centrifugal force-based training has varying effects on the biomechanical indicators examined. In general, the variables of pre-hurdle distance, post-hurdle distance, and 400m hurdle run time showed statistically significant improvements with large effect sizes, while the variables of centrifugal force and smoothness index showed moderate but non-significant effects, and the kinetic rhythm variable showed a small effect.

Based on the results in Table 2, the centrifugal force variable showed an increase in the mean value from 103.108 on the pre-test to 105.168 on the post-test, with a difference of 2.059, a calculated t-value of 1.409, and  $p = 0.218$  ( $p > 0.05$ ). Although this difference is not statistically significant, Cohen’s d value of 0.58 falls into the moderate effect category, and the

percentage increase of 1.997% indicates a practically meaningful trend toward improvement. The researchers suggest that this increase in centrifugal force is the result of improved muscle responses during cornering. Specific training designed to reduce the turning radius (from 33 m to 30–32 m) forced the small muscles involved in cornering to work under the influence of greater centrifugal force.

This is consistent with the view (Usherwood & Wilson, 2005) that centrifugal force increases as the turning radius decreases at a constant speed. Training with a smaller radius accustoms runners to running at high speeds, with longer strides, and a greater degree of inward body lean. This mechanism forces runners to activate the hip and ankle stabilizing muscles more intensively, particularly the gluteus medius and tensor fasciae latae on the left side (since the runner is running counterclockwise around the curve) as well as the peroneus longus muscle on the right leg to maintain stability while resisting inward movement (Chang & Kram, 2007; Churchill et al., 2015).

The lack of statistical significance for this variable is most likely due to the small sample size ( $n=6$ ), which increases the risk of a Type II error (i.e., failing to detect a difference that actually exists). Post-hoc analysis indicates that to achieve a statistical power of 0.80 with a moderate effect size ( $d=0.50$ ), a minimum sample size of 18 participants is required (Cohen, 1988; Field, 2018). Thus, a 2% increase in centrifugal force, although not statistically significant, still indicates a relevant positive trend in the context of improved athletic performance, especially given that the intervention lasted only 9 weeks (Hopkins, 2000).

The study results show that the pre-goal distance variable increased significantly from 1.801 m to 1.841 m ( $MD = 0.040$ ;  $t = 2.739$ ;  $p = 0.041$ ) with a very large effect size (Cohen's  $d = 1.08$ ). This finding is both statistically and practically significant. The pre-hurdle distance primarily depends on the runner's running speed as they approach the hurdle. The faster the runner, the longer the ideal pre-hurdle distance, as approaching the hurdle too closely causes a loss of speed and a lack of fluidity in movement (Hunter et al., 2005). Approaching the hurdles too closely also causes the body's center of mass to rise higher while clearing the hurdles, thereby increasing the time required to clear them (Mero & Komi, 1985; Salo et al., 2011).

The significant increase in the distance to the goal in this study was associated with an improvement in the ability of the leg extensor muscles to generate greater power. Centrifugal-based training with a 2% additional load on the right leg (as in exercises T1 and T6) stimulates increased activation of fast-twitch motor units in the quadriceps, hamstrings, and gluteus maximus muscles. According to Bompa & Haff (2009) and Enoka (2015), increased muscle strength and contraction speed allow runners to lengthen their stride without reducing stride frequency, thereby achieving an optimal point of contact before the hurdle.

This aligns with the findings of (Abdul Karim et al., 2010), who stated that stride length is controlled by the propulsive force when the foot contacts the ground, as well as the angle of the force formed with the ground surface. The results of the study indicate that the post-hurdle distance decreased significantly from 1.196 m to 1.170 m ( $MD = -0.026$ ;  $t = 3.162$ ;  $p = 0.025$ ) with a very large effect size (Cohen's  $d = 1.08$ ). A decrease in post-hurdle distance is a positive indicator because it suggests that runners are able to land closer to the hurdle, meaning running speed can be better maintained. Post-hurdle distance depends on mechanical variables over the

hurdle, including the height of the body's center of mass as it passes the hurdle and the speed of the trailing leg's pull.

According to Hamill & Knutzen (2009) and Novacheck (1998), the ability to quickly pull the back leg back after passing the hurdle allows the runner to immediately extend the trunk and quickly pull the leg forward along the transverse axis of the pelvis. This movement is caused by rapid contraction of the gluteal muscles and contraction of the quadriceps muscles, which results in knee joint extension. Centrifugal-force-based exercises designed with smaller turning radii (30 m in exercises T4 and T6) and the addition of hurdles in the exercises (T3, T4, T5, T7) effectively train the core muscles and hip flexor muscles to work faster and more efficiently under centrifugal force conditions.

(Schmidt & Wrisberg 2008) state that training under balance-challenging conditions (such as running on a curve with the body leaning inward) improves neuromuscular coordination and reduces reaction time. This explains why the runners in this study were able to significantly shorten the distance after the hurdles. The results show that the kinetic rhythm variable changed from -0.597 to -0.589 (MD = -0.007;  $t = 1.333$ ;  $p = 0.240$ ) with a small effect size (Cohen's  $d = 0.22$ ). This difference is not statistically significant and indicates a limited effect of the intervention.

The kinetic rhythm, calculated using the formula (ground contact time / flight time) – 1, indicates a balance between the ground contact phase and the flight phase. Values approaching -0.5 to -0.6 indicate that the flight phase is slightly longer than the ground contact phase, which is a characteristic of efficient hurdle running (Winter, 2009; McGinnis, 2013). The very small change (0.008) observed in this study indicates that a 9-week training period was insufficient to alter the underlying rhythm pattern established through years of training. According to Abdul Karim et al. (2018) and Issurin (2008), changes in movement rhythm require a longer training period (at least 12–16 weeks) because they involve more complex central nervous system adaptations compared to changes in muscle strength alone.

In addition, kinetic patterns are influenced by anthropometric factors such as leg length and height, which are relatively constant in a sample of late adolescents (Hunter et al., 2005). Thus, the non-significance of these findings does not imply that the exercise was ineffective, but rather that this indicator may require a longer intervention duration or a more sensitive measurement method to detect meaningful changes. The results showed that the smoothness index increased (approaching zero) from -12.859 to -10.448 (MD = -2.410;  $t = 1.998$ ;  $p = 0.102$ ) with a moderate effect size (Cohen's  $d = 0.58$ ). Although not statistically significant, this 18.7% increase has considerable practical significance.

The fluidity index, calculated from the difference in momentum between the take-off phase and the landing phase, reflects the extent to which the runner's motion as they pass through the hurdles is smooth and without loss of momentum. According to (Abdul Karim et al., 2010), the smoothness index is related to all components of force impulse, including force moment, force duration, force frequency, and force rhythm. An index close to zero indicates a smoother flow of motion. The increase in the smoothness index in this study was due to additional weight training on specific body parts (2% of the right leg's mass), enabling the runner to generate an appropriate force impulse.

In addition, training with a smaller turning radius affects the approach angle and takeoff angle when passing through the goal. (Enoka, 2015) explains that applying a small load to specific body segments (known as load training) can improve proprioception and body position awareness, which in turn enhances movement efficiency. This aligns with findings indicating that the smoothness index is associated with all components of instantaneous momentum, including time moment, time duration, time frequency, and time rhythm. The difference in results between this study and the study by Al-Fadhli (2010), which found significant changes in the smoothness index after eccentric resistance training, is likely due to differences in intervention duration (9 weeks vs. 12 weeks) or the intensity of the additional load (2% of right leg mass vs. 5% of total body mass).

Further research with a longer duration and a wider range of loads is recommended to confirm these effects. The results in Table 3 show that the 400m hurdles race time decreased significantly from 62.34 seconds to 60.12 seconds (MD = -2.22 seconds;  $t = 3.451$ ;  $p = 0.018$ ) with a very large effect size (Cohen's  $d = 1.07$ ). This finding is statistically and practically significant and is the most important finding in this study because race time is the primary indicator of success in the 400m hurdles race. An improvement of 2.22 seconds (approximately 3.6%) over a 9-week period represents a highly meaningful improvement in the context of competitive sports.

According to (Bompa & Haff, 2009), a 1–2% improvement in performance over 8–12 weeks is considered good for advanced athletes. A 3.6% improvement indicates that centrifugal-based training interventions are highly effective. This reduction in race time is the cumulative result of improvements in the biomechanical variables discussed earlier. An increase in the distance before the hurdles and a shortening of the distance after the hurdles contribute to a reduction in the time lost while passing each hurdle. Given that the 400m hurdles race has 10 hurdles, a time savings of 0.1-0.2 seconds per hurdle would accumulate to 1–2 seconds overall (Mero & Komi, 1985; Susanka & Stepanek, 1980).

In addition, training on tighter turns improves runners' ability to maintain high speed through turns, which is the weakest segment for most 400-meter hurdlers (Salo et al., 2011). Researchers argue that the greatest contribution of centrifugal-based training lies in improving cornering-specific speed and cornering-specific speed endurance. This is due to the targeting of specific muscles that work when running through turns, namely the ankle stabilizer muscles on the outer side of the right foot and the hip flexor muscles on the inner side of the left foot. The resulting neuromuscular adaptations allow runners to maintain a higher stride frequency throughout the race, particularly during the final 200 meters where fatigue typically begins to set in (Churchill et al., 2015; Chang & Kram, 2007).

## Conclusion

Based on the research findings and discussion presented regarding 6 junior 400m hurdlers (under 20 years of age) at the National Sports Talent Development Center in Baghdad Province, the following conclusions can be drawn: First, the research hypothesis is partially accepted. The variables showing statistically significant differences at the  $\alpha = 0.05$  level are the average distance before passing the hurdles ( $p = 0.041$ ; Cohen's  $d = 1.08$ ), the average distance after

passing the hurdles ( $p = 0.025$ ; Cohen's  $d = 1.08$ ), and the 400m hurdle run time ( $p = 0.018$ ; Cohen's  $d = 1.07$ ). These three variables fall into the large effect category according to Cohen's criteria, indicating that centrifugal-style training exerts a very strong influence on these aspects.

Second, the hypothesis was rejected for the centrifugal force variable ( $p = 0.218$ ; Cohen's  $d = 0.58$ ), the biomechanical kinetic rhythm of the hurdle step ( $p = 0.240$ ; Cohen's  $d = 0.22$ ), and the hurdle step smoothness index ( $p = 0.102$ ; Cohen's  $d = 0.58$ ). Nevertheless, the centrifugal force and smoothness index variables showed moderate effects with average increases of 2.0% and 18.7%, respectively, which have practical significance in the context of athletic performance even though they did not reach statistical significance. This lack of significance is most likely due to the small sample size ( $n=6$ ), resulting in the study lacking sufficient statistical power to detect differences that may actually exist.

Third, centrifugal force-based training using the principle  $F = m \cdot v^2/r$  proved effective in modifying specific technical aspects, particularly stride length before and after the goal, as well as overall travel time. However, there is insufficient evidence to state that this training significantly affects all biomechanical variables studied, given the limitations of sample size and intervention duration. In other words, this physics-based training approach is more effective for variables directly related to muscle strength and power, compared to variables related to complex neuromuscular coordination such as rhythm and fluidity of movement.

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