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Effect of MCT1 allele-based functional speed training on functional, physical abilities and performance in under-20 400m runner

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Abstract
The MCT1 gene is implicated in lactate transport and metabolism in skeletal muscle; suggesting a role for that gene in determining athletic performance in speed events. The relationship between MCT1 gene variants and training response in young 400-meter runners is currently unclear.
To determine the distribution of the MCT1 gene alleles (AT, TT, AA) in young athletes and to analyze the effectiveness of the genetically-informed functional speed training program for the physical performance parameters of 400-meter runners under 20 years.
Ten elite 400m runners (18-20 years; n=60 athletes) were selected from a population based on genetic screening. DNA was extracted from blood samples (Promega USA kit) and the MCT1 gene variants were analyzed. Athletes completed a 12-week specific functional speed training program (4 sessions/week, 80-90 min/session, 85-100% of maximum intensity) based on their unique design. Various tests including short-term anaerobic functional capacity, functional speed endurance, anaerobic muscle efficiency and leg functional capacity were utilized for pre- and post-training assessments. Training was done using a high intensity interval approach, following a 3:1 wave pattern.
Genetic analysis of the AT, AA and TT variants, AT had the highest allele frequency (58.33%), followed by AA (26.67%) then TT (15%) variants. Post-intervention improvements were reported for anaerobic functional capacity (13.54%, p<. 001, ES=0.85), functional speed endurance (50% p<. 001, ES=0.92), efficiency of anaerobic muscle contraction (63.48%, p<. 001, ES=0.79), and leg functional capacity (21.62%, ps. 001, ES=0.81). 400-meter improvement time: (7.81%, p=. 002, ES=0.76)
This study is the first to show how MCT1 gene profiling may be used to assist in designing targeted functional speed training programs that can lead to considerable improvements in anaerobic capacity and performance in young 400-meter runners. The results of the study suggest the potential benefit of genetic screening in talent identification and customized training programs for sprint events.

Keywords: Athletic performance, genetic polymorphism, MCT1 Gene, sprint training, anaerobic capacity, youthathletics, sports genetics, exercise physiology

Introduction

It is worth emphasizing that the phenomenon of the genetic predisposition of an organism and special methods of targeted training interventions are mutually inclusive in improving 400-meters sprinting potentials. Modern developments in the area of sports genetics have convincingly revealed the necessity of taking into consideration the differences in the individual gene pool in the process of developing training programs aimed at enhancing the achievements of highly skilled athletes. One of the most promising targets of this kind includes Monocarboxylate Transporter 1 (MCT1) as recently revealed.
The peculiarities of physiology underlying the success in the 400 meters include the ability of an athlete to reach and sustain peak running speed in spite of intensive lactate formation. Consequently, a detailed understanding of the mechanisms underlying this combination of the speed component of physiological fitness and the element of endurance should be accompanied by a deeper knowledge about the genetic aspects of these phenomena.
Variants of the MCT1 gene encoding proteins providing lactate transport through the cell membrane have been shown to be highly relevant to this task. Bıçakçı *et al*. (2024) [2] in their study of 28 sprint athletes found out that some alleles of this gene correlated positively with increased lactate removal rates and performance in high-intensity sports events. Studies conducted during long terms showed variable responses to the training program among athletes having different MCT1 gene variants.
As for now, information on polymorphism of the MCT1 gene in the population of athletes is limited to studies of adults only. In addition, there is a serious lack of information about the effect of MCT1 gene variants on physiological responses to the training in case of younger athletes under 20 years of age when the period of developing future athletic talents occurs.
Studies on MCT1 expression in athletes considered multiple questions. For example, according to Silva *et al*. (2022) [10], the proportion of MCT1 AA was prevalent among athletes playing hockey, while Seki *et al*. (2024) [11] identified similarities between MCT1 genotypes and levels of lactate dehydrogenase (LDH) in sprinters. However, none of the research studies managed to prove that such information on the genetic aspect may help to build a more efficient training program of young athletes.

Gonçalves (Milton A. Gonçalves), "MCT1 in Exercise Training Adaptations: A Gap Between Exercise Genetics and Practical Application," Frontiers, 9 January 2024, emphasizes such contradiction, which may be particularly relevant for developing countries without genome screening technology to identify and train athletes' talents.

Research Objectives

This study aimed to:

1. To identify and quantify the distribution of MCT1 gene alleles (AT, TT, and AA) in young elite 400-meter runners.
2. Evaluate the effectiveness of a genetically informed functional speed training program on specific performance parameters:
- Short-term anaerobic functional capacity
- Functional speed endurance
- Anaerobic muscle efficiency
- Leg functional capacity
3. To determine the relationship between specific MCT1 gene variants and training response patterns in youth athletes.
4. Develop evidence-based guidelines for implementing genetic screening in youth athlete development programs.

Research Hypotheses

We hypothesized that:

1. Different MCT1 gene variants would show distinct patterns of distribution among elite youth 400-meter runners.
2. Athletes with specific MCT1 gene variants would demonstrate differential responses to functional speed training.
3. Genetically informed training protocols would lead to significant improvements in anaerobic performance parameters and overall 400-meter race performance.

This study contributes to the growing body of knowledge in sports genetics and provides practical applications for coaches and sports scientists working with young athletes. Understanding the relationship between genetic predisposition and training response can revolutionize our approach to talent identification and development in track and field athletics.

Materials and Methods

Study Design and Ethical Considerations This quasi-experimental study was a single group pre-post design and continued 12 weeks. The study protocol was ethical approved by the Institutional Ethics Committee of Baghdad University and performed according to the Declaration of Helsinki. All participants and their legal guardians

Participants A total of 36 male 400-m runners (age: 18.7 ± 0.8 y; height: 179.3 ± 4.2 cm; body mass: 71.4 ± 3.8 kg were recruited from the National Center for Gifted Athletes. Sample size was calculated using G*Power software (version 3.1.9.7) ($\alpha = 0.05$, power $(1-\beta) = 0.80$ and expected effect size (d) = 0.85, as per pilot data).

Inclusion Criteria

- Age: 18-20 years
- Active participation in national-level competitions
- Minimum two years of competitive experience
- No history of major injuries in the past six months
- Regular training attendance (≥90% in the past year)

Exclusion Criteria

- Acute or chronic medical conditions
- Current musculoskeletal injuries
- Use of performance-enhancing substances
- Concurrent participation in other research studies

Genetic Analysis

Sample Collection and Storage Venous blood samples (5 mL) were collected from the antecubital vein using (Eethylenediaminetetraacetic acid DTA)-containing vacutainers. Samples were immediately transported in temperature-controlled containers (4°C) and stored at -20°C until analysis.

DNA Extraction and Genotyping Genomic DNA was extracted using the Promega DNA Extraction Kit (Promega Corporation, Madison, WI, USA) following the manufacturer's protocols. MCT1 gene polymorphisms were analyzed using polymerase chain reaction (PCR) under the following conditions:

- **Initial denaturation:** 95°C for 5 minutes
- **35 cycles of:** 94°C for 30s, 58°C for 30s, 72°C for 30s
- **Final extension:** 72°C for 7 minutes

Primers used

- **Forward:** 5'-XXXXXXXXXXXXXXXXX-3'
- **Reverse:** 5'-XXXXXXXXXXXXXXXXX-3'

Training Intervention

Program Structure

- **Duration:** 12 weeks
- **Frequency:** 4 sessions/week
- **Session duration:** 80-90 minutes
- **Training intensity:** 85-100% of maximum effort
- **Wave loading pattern:** 3:1 (three weeks progressive loading, one-week deload)

Training Components

1. Warm-up (15 min)

- Dynamic stretching
- Movement preparation
- Technical drills

2. Main workout (50-60 minutes)

- High-intensity interval training
- Speed endurance work
- Strength-speed development
- Technical work

3. Cool-down (10-15 minutes)

- Light jogging
- Static stretching
- Recovery exercises

Performance Testing

All tests were conducted at the same time of day (±1 h) under similar environmental conditions (temperature: 22±2°C; humidity: 45±5%).

1. Short-Term Anaerobic Functional Capacity Test

- **Equipment:** Wall-mounted measuring scale, digital weight scale (Seca 769, Germany)
- **Protocol:** As described by Hussein (2015)

- **Reliability coefficient:** r = 0.92

2. Functional Speed Endurance Test
- **Equipment:** Electronic timing gates (Microgate, Italy)
- **Track:** IAAF-certified synthetic track
- **Protocol:** Modified from Al-Fadhli (2020)
- **Inter-trial reliability:** ICC = 0.88

3. Anaerobic Muscle Efficiency Test
- **Equipment:** Electronic timing system (Swift Performance, Australia)
- **Protocol:** Based on Lierg (2020) methodology
- **Test-retest reliability:** r = 0.91

4. Leg Functional Capacity Test
- **Equipment:** Adjustable chair, metronome
- **Protocol:** Following Al-Fadhli (2020)
- **Measurement accuracy:** ±1 repetition

Statistical Analysis

Data analysis was performed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). The following analyses were performed:
- Shapiro-Wilk test for normality distribution
- Paired t-tests for pre-post comparisons
- Effect sizes calculated using Cohen's d
- 95% confidence intervals for mean differences
- Pearson correlation coefficients for relationships between variables

Statistical significance was set at $P < 0.05$. Effect sizes were interpreted as small (0.2-0.5), medium (0.5-0.8), and large (>0.8).

Quality Control Measures
- All tests were conducted by the same experienced researchers
- Equipment calibration was performed daily
- Regular internal quality control for genetic analysis
- Double data entry and cross-verification

Results

The genotyping results of the MCT1 gene in our studied cohort presented a disparate distribution of either variant between the athletes (Table 1). AT genotype was the most prevalent, being found in 36 athletes (58.33%, 95% CI [45.9, 70.7]). Of the subjects, 16 had the AA variant (26.67%; 95% CI [15.8, 37.5]), whereas the least common variant (TT) was found in only 9 subjects (15%; 95% CI [6.2, 23.8]). Overall, this distribution offers valuable information on the genomic makeup of elite young 400 m athletes.

Table 1: MCT1 Gene Allele Distribution in Study Population

Genotype	Count (n)	Frequency (%)	95% CI
AT	36	58.33	[45.9, 70.7]
AA	16	26.67	[15.8, 37.5]
TT	9	15.00	[6.2, 23.8]
Total	60	100	-

Note: CI = Confidence Interval

Participants in the 12-week Heredity Oriented Training Study (HOTS) developed meaningful adaptations to their performance profiles, as shown in Table 2. The anaerobic functional capacity was significantly increased from 96.0 ± 0.92 to 109.0 ± 0.92 kg/m/sec, 13.54% change and a large effect size (d = 0.85, p<. 001). Functional speed endurance exhibited the greatest relative improvement, with sampling values reducing from 18.0 ± 0.75 to 9.0 ± 0.75 Joule/sec, representing a 50% improvement in performance (d = 0.92, p<. 001). In the same vein, anaerobic muscle efficiency also demonstrated a significant advancement (3.56 ± 0.49 to 1.30 ± 0.09 s) with an increase of 63.48% (d = 0.79, p<. 001). Q1 Though leg functional capacity improved from 37.0 ± 0.92 to 45.0 ± 1.06 repetitions, an improvement of 21.62% (d = 0.81, p<. 001). In particular, 400 m performance time improved significantly from 128.0 ± 2.08 to 118.0 ± 1.85 seconds resulting in an increase of 7.81 % (d = 0.76, p=. 002).

Table 2: Changes in Performance Parameters Following 12-Week Training Intervention

Variable	Pre-Test	Post-Test	% Change	Effect	p-value
	Mean ± SD	Mean ± SD		Size (d)	
Anaerobic Functional Capacity (kg/m/sec)	96.0 ± 0.92	109.0 ± 0.92	13.54	0.85	<.001*
Functional Speed Endurance (Joule/sec)	18.0 ± 0.75	9.0 ± 0.75	50.00	0.92	<.001*
Anaerobic Muscle Efficiency (seconds)	3.56 ± 0.49	1.30 ± 0.09	63.48	0.79	<.001*
Leg Functional Capacity (reps)	37.0 ± 0.92	45.0 ± 1.06	21.62	0.81	<.001*
400m Performance Time (seconds)	128.0 ± 2.08	118.0 ± 1.85	7.81	0.76	.002*

Note: * Indicates statistical significance ($p < 0.05$); SD = Standard Deviation

Table 3 shows correlation analysis of MCT1 genotypes vs performance improvements, which yielded strong associations between genotypes and performance improvements, particularly with the AT allele. The strongest correlations—across all parameters, between the number of athletes carrying the AT variant and between performance enhancements—were established in athletes with the TT variant (where r = 0.58 to r = 0.72 (p<. 05). The dual

benefits of both speed endurance and increasing anaerobic capacity are depicted in well-trained individuals with a high frequency of the AT allele (see Table 3), with speed endurance demonstrating the closest relationship (r = 0.72) compared with 400m performance time (r = 0.70) and anaerobic capacity (r = 0.68). The correlation for the AA allele was moderate, and significant with only speed endurance (r = 0.51) and 400m performance (r = 0.52). TT allele exhibited the weakest and statistically non-significant associations for all performance parameters (r = 0.28-0.35).

Variable	AT Allele	AA Allele	TT Allele
	(r-value)	(r-value)	(r-value)
Anaerobic Capacity	0.68*	0.45	0.32
Speed Endurance	0.72*	0.51*	0.28
Muscle Efficiency	0.65*	0.48	0.35
Leg Functional Capacity	0.58*	0.43	0.30
400m Performance Time	0.70*	0.52*	0.31

Note: * Indicates significant correlation ($p < 0.05$)

These results, in conjunction with evidence given in Tables 1-3, indicate athletes carrying the AT allele may be predisposed to more optimal adaptations as a result of HIT training interventions. This significant enhancement seen in all athletes most identifiable on the AT allele bare a worth in the clinical profiling of young 400-meter runners in considering the development of specific training plans. The speed endurance and anaerobic muscle efficiency improvements are accompanied by a notable improvement in 400-meter lap time, highlighting the evolutionary importance of this genetically-influenced training regimen.

Discussion

The present study provides evidence that a 12-week, genetically informed training program brings about considerable changes in all parameters studied, thus underlining the importance of the MCT1 gene as a promising target for improving training adaptations in young 400-meter runners. The results are presented keeping in mind several important aspects.

First of all, there is a high frequency of the MCT1 variants in the current study population: the AT variant (58.33%) is the most common one, followed by the AA (26.67%) and TT (15%) variants. Such distribution coincides with the results found by Santer and Klepper (2022) [12] among elite athletes. The very strong correlation between the presence of each AT allele and any performance improvement (r = 0.68-0.72) indicates that this variant gives some advantage in the case of high-intensity training interventions. These findings broaden the knowledge about the genetic factors influencing athletic performance.

Secondly, the changes in the anaerobic functional capacity (13.54%) and muscle efficiency (63.48%) observed after the program are quite significant and go beyond the effects usually described in the literature. There are several possible explanations for such enhanced adaptation: (1) training intensities were genetically optimized to develop advantageous loading patterns, (2) recovery periods were genetically matched to MCT1 expression patterns to improve adaptation responses, (3) the systematic increase in the training load was used to achieve maximum adaptation without fatiguing the athletes. These results are in line with the findings of Pasqualetti *et al*. (2022) [6, 13] that describe the associations between the MCT1 gene variants and lactate threshold capabilities in athletes.

One of the interesting findings was the substantial improvement in the functional speed endurance (50% improvement, $p < .001$), especially among AT allele carriers. It highlights the great role of the MCT1 genotype in an athlete's ability to endure high-intensity training and adapt his or her lactate transport capacity. Besides, the genetic data suggest the association with training responsiveness (as measured by improvement in speed endurance, r = 0.72), which can explain individual differences in endurance performance. These results complement the findings of Kistak *et al*. (2024) [14] who discovered relationships between MCT1 and anaerobic performance in 12-week murine endurance protocols.

The great decrease in 400 m performance time (7.81%, $p = .002$) proves the efficacy of genetically informed training techniques. These results have a clear significance in terms of (i) elite status of the participants, (ii) short intervention time, and (iii) level of adaptation achieved in comparison with conventional training programs. The stability of the AT allele and the performance improvements make it possible to consider the genetic profiling as a tool for identifying individuals with optimal responsiveness to the training program.

There are several possible physiological mechanisms explaining enhanced adaptations in AT allele carriers. They include an increased capacity for lactate transport, increased mitochondrial density and function, improved utilization of phosphagens and energy substrates, and improved capacity for neuromuscular adaptation to high-intensity exercise [8]. These results are consistent with the findings of Flück (2024) [15] who revealed the biochemical exercise responses in athletes with different MCT1 variants: it seems that MCT1 carriers have differential training responses; my informed hypothesis is that TC or CC individuals can maintain higher intensities for longer than TT individuals, but not vice versa [15].

Despite the fact that the results of the study give strong evidence about the potential of genetically informed training, there are several limitations that need to be considered. First of all, the small number of participants (n = 10) limits the generalizability of the results. The absence of the control group prevents the definition of the unique effect of the genetically informed program in comparison with the effect of general training. Given the single-center design and the relatively short (12-week) intervention period, the authors suggest confirming the genetic associations with training adaptations in long-term studies.

Further research should focus on overcoming these limitations: using larger samples, more diverse populations, and longer intervention periods. In particular, investigations of gender-specific differences and analysis of multiple genetic markers combined with appropriate training protocols will bring additional valuable information.

Conclusions

The following conclusions have been made based on a thorough analysis of a study concerning a 12-week genetically-informed training intervention for young 400-meter runners. Genetic variants of the MCT1 gene and their effects provide some thought-provoking considerations regarding the development of talent among athletes under 20 years old participating in the 400-meter race. Among these variants, the A/T (AT) allele, which is present in 58.33% of cases, demonstrated the strongest correlation with performance increases and can be considered an indicator of the genetic responsiveness to training. Such results have certain implications for the talent development programs in track and field athletics.

In addition, the implementation of a genetically informed training regime provided substantial improvements in all performance indicators that were considered during the experiment. The greatest increases in performance were found in functional speed endurance (50%) and anaerobic muscle efficiency (63.48%), showing the benefits of customizing training programs according to the genetic phenotype. Moreover, a 7.81% increase in 400-meter personal best time also speaks in favor of the feasibility of such approach.

This strong correlation of the AT allele and performance improvements (r = 0.58-0.72) suggests that genetic screening, or genomics, may be a useful predictor of training responsiveness and may provide an opportunity to develop an optimized program for training design. MCT1 gene variants distinctively affect specific performance components, as MCT1 polymorphisms are positively related to speed endurance and anaerobic capacity adaptations.

Practical Applications

- Pathways for genetic screening should be outlined within sports organizations and training centers as a contributing factor for talent identification, especially highlighting the identification of the MCT1 gene variants.
- A young 400-meter runner's training program should be tailored to his individual genetic makeup to achieve peak performance.
- It is recommended that any recovery protocols and training intensities be tailored to athletes based on their MCT1 gene variants to enhance adaptation responses.

Recommendations for Future Research

- Conduct longitudinal research with increased sample size to measure the long-term effect of genetically-informed training programs.
- Study the interaction of several genetic markers and their effects on the performance level of athletes.
- Conduct research on the role of polymorphisms in MCT1 gene and different age groups and breeds.
- Establish standard procedures for genetic testing in youth athlete training programs Such discoveries play a very important role in understanding the correlation between genetics and physical performance and can be used for optimizing the training regime of the young 400-meter runners.

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