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The Influence of Gene Polymorphysms and Genetic Markers in the Modulation of Sports Performance: A Review

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ABSTRACT

Castilha FA, Ferreira HR, Oliveira G, Oliveira T, Roquetti Fernandes P, Fernandes Filho J. The Influence of Gene Polymorphysms and Genetic Markers in the Modulation of Sports Performance: A Review**. JEPonline** 2018;21(2):248-264. This study is a review of the influence of the R577X polymorphisms of the ACTN3 gene, I/D of the angiotensin converting enzyme (ACE) gene and dermatoglyphics in the modulation of sports performance. The focus is on presenting the two genes and their role in athletic performance that requires muscular strength and power. As to the dermatoglyphics, this study looks at the different fingerprint variables and correlates them with sport performance. The initial survey involved data from 966 articles. Sixty-two were used as the basis for this study. The findings suggest that the presence of the α-actinin-3 isoform is beneficial to strength and power sports, while its absence seems to benefit endurance athletes. Regarding the ACE activity, the studies indicate that individuals who present the D allele of the ACE show a greater genetic predisposition to gain muscle strength after a strength training season, which may be related to the improvement of neural adaptations and muscle hypertrophy. As for dermatoglyphics, it seems to be a powerful tool for understanding individual differences, potentialities, strengths and weaknesses in sport, as well as the genetic limitations that may impair or help to improve the athlete's training and performance.

Key Words: ACTN3, ACE Gene, Dermatoglyphics, Sports

INTRODUCTION

A genetic marker represents any morphological or molecular characteristic that is detectable and differs among individuals. A genetic polymorphism is defined as nucleotide bases that differ from those considered "normal", which represent a lower frequency in a given population (31).

Ostrander et al. (47) affirm that the differentiated gene sequences, polymorphisms, can influence protein expression and modify characteristics that alter sports performance. Thus, to reach a maximum athletic performance, the influence of genetics on physical performance has been studied in a more exploratory and stratified way, allowing the selection of specific regions of interest. Considering the causal analysis between DNA and physical performance, it is interesting to study the sources of variation in the genotype that are capable of causing phenotypic differences relevant to sports performance.

The study of polymorphism has been highlighted in sports sciences due to its practical application and influence on sports performance success (58). Macarthur and North (37) indicate these studies have shown that genetic factors can determine from 20% to 80% the variations found (37). In fact, Bray et al. (9) report that there are currently more than 200 genetic variations potentially associated with physical performance phenotypes, and about 20 polymorphisms associated with elite athletes (9).

Among the polymorphisms, which may influence physical performance the R577X of the ACTN3 gene and angiotensin converting enzyme (ACE) are the most commonly investigated. From information related to genetic variability, it is suggested that these genes possibly express proteins that potentiate sports performance (20,49).

The identification of genetic markers that can promote athletic success seems to be a good strategy in sports, since individualized training may stimulate specific metabolic pathways that will contribute towards the development of specific physical qualities, such as endurance, strength, and/or power (32,49). It is worth mentioning that although the entire human genomic sequence has been identified, very little is still known regarding the influence of genetic polymorphisms on sports performance (20). Proof of this lies in the fact that out of the 30,000 genes identified in human DNA, just over 200 genes are known to have a relationship with performance (9).

In addition, it should be noted that scientific evidence indicates that it is possible to find genetic characteristics and guide physical training from dermatoglyphic markers (25). Considered to be a non-invasive, low-cost, and proven efficacy technique in several studies, dermatoglyphics have been used to identify optimal profiles for the development of physical abilities (5,34) in high-level sports performance.

Therefore, the present work will review the literature in order to identify the influence of the R577X polymorphisms of the ACTN3 gene, I/D of the angiotensin converting enzyme (ACE) gene, and dermatoglyphic markers in the modulation of sports performance. This review is intended to address knowledge about the importance of genetic markers, polymorphisms, and dermatoglyphics in phenotypes related to human physical performance for elite athletes. The focus is on presenting the genes with the potential to influence the performance of athletes in sports that require resistance, muscular strength, and power. The biological mechanisms of each will be discussed, especially how polymorphism contributes towards the characterization of elite athletes. As for the dermatoglyphic markers, the primary focus is to present the different fingerprint variables and correlate them with sport performance.

METHODS

This is a review article in which a search was made at the following databases: Web of Science, Scopus, Medline, Scielo, and Pubmed with the following keywords: “ACTN3 gene”, “ACE gene”, “Sports performance”, and “dermatoglyphics”. The inclusion criteria consisted of a survey that covered published articles from 1990 to 2017 of which 966 articles were initially found in the survey. 533 articles were excluded after reading the titles, leaving a total of 433 articles. After reading the abstracts, 295 additional articles were excluded, leaving 138 articles in total. Then, after reading the texts, 76 more articles were excluded, and the selection was finalized with 62 articles, which were used as the basis for the construction of this review article.

RESULTS

The 577x A-Actinin 3 Gene Polymorphism (ACTN3) and the Sport Performance

The high-level performance in sports that requires strength and/or power is directly related to the distribution of the athlete’s muscle fiber type (3). It is known that skeletal muscle type I and type II fibers have a direct relationship with physical exercise (8). These fibers hold different characteristics, which can be explained by the expression of genes that modulate specific responses regarding muscle contraction, enzymatic activity, morphology, and metabolism (4). In addition, they adapt to physical training by altering their size and metabolic characteristics (50,52).

The α-actinin-3 integrates the α-actinin family, actin-binding proteins. Its structure is basically made out of 3 domains: (a) an amino-terminal that binds to actin; (b) a central with four repeated spectrum homologous sites; and (c) a third domain in the final portion containing a carboxyl with two calcium binding sites (6). Studies have shown the presence of α-actinin-3 in the muscle (RR or RX genotypes), that is, the absence of polymorphism, benefits performance in activities that require mainly strength and muscle power (21,60). On the other hand, the absence of α-actinin-3 protein in the muscle (genotype XX), which characterizes the polymorphism, is favorable to performance in endurance events (46).

In an attempt to demonstrate the association between genotypes, ACTN3 gene allelic frequency, and the effects on sports performance, Yang et al. (60) analyzed the genotypic frequencies of ACTN3 in athletes of both genders in strength and power sports and endurance sports. The athletes were also compared to a group of healthy, non-athletes; all genotyped for the ACTN3 gene. The results showed that there was a lower incidence of genotype XX for strength and power athletes when compared to non-athletes (6% versus 18%, respectively).

Also, in Yang et al. (60), when analyzed in general numbers, the strength and power athletes (107 athletes) show a higher incidence of the RR genotype along with a lower frequency of the RX genotype (50% and 45%, respectively). The key part of the research was the comparison between strength and power athletes with resistance athletes who showed allelic frequency in opposite directions, values which were significantly different for both genders. The frequency of genotype XX in the men group was 20% for endurance athletes and 8% for strength and power athletes. In the women group, the genotype XX frequency was 29% for endurance athletes, and 0% for strength and power athletes. The frequency of the RR genotype in men was 28% for endurance athletes, and 53% for strength and power athletes; whereas, in women the RR genotype frequency was 36% for endurance athletes and 43% for strength and power athletes. These findings suggest that the results are a consequence of the greater capacity of absorption and transmission of force in the Z line of the type II fibers in the subjects the RR and RX genotype compared with the XX during the fast contractions.

Similar results were found by Niemi and Majamma (46), who tested two groups of athletes (52 endurance and 89 sprinters). They found that the frequency of XX genotype increased according to the competitive level of endurance athletes, but decreased significantly in the strength and power athletes. On the other hand, although the RR genotype showed a high frequency in all groups, the value was lower in the endurance athletes when compared to the sprinters.

Druzhevskaya et al. (20) analyzed the R77X polymorphism of the ACTN3 gene in Russian athletes of different strength and power sports, and then they compared their findings with non-athletes. The frequencies of the X allele and the XX genotype were higher in non-athletes (38.7% and 14.2%, respectively) when compared to strength and power athletes (33.3% and 6.4%). This corroborates with most findings that the X allele frequency is lower in athletes who require great strength and power in their sports.

In a study developed by Eynon et al. (23) with 633 elite European athletes (278 endurance athletes and 355 strength and power athletes) and 808 non-athletes, it was noted that strength athletes were less likely to have the polymorphic genotype (XX) while the endurance athletes were 1.88 times more likely to have the XX genotype versus the RR genotype. Interestingly, for the endurance athletes, the likelihood of presenting genotype XX was about 3.7 times higher for high performance athletes when compared to the low-level athletes. The findings in their study corroborate with the findings throughout the literature, and show a favorable tendency for the resistance activities regarding genotype XX. This suggests that the ACTN3 gene may have a greater influence on high performance levels.

In a recent study by Yamak and colleagues (59), the relationship between the performance of elite Turkish athletes and the polymorphic α-actinin-3 gene was investigated in 300 subjects (150 elite athletes and 150 sedentary individuals). It was found that the frequency of XX genotypes among the sedentary individuals was lower than in the elite athletes (P=0.03). The RR + RX frequencies were higher in the athletes group, and differed significantly (P=0.0011) between the two groups. Their findings support the differences among athletes and non-athletes regarding genotypes, thus indicating that the presence of the ACTN3 gene is related to sports performance among strength and power athletes.

With regards to strength indicators, individuals with a homozygous genotype for the R (RR) allele present higher levels of strength, according to Vicent et al. (54), who genotyped 44 healthy men for the ACTN3 gene (22 with homozygous genotypes XX and 22 homozygous

RR), all without previous history of strength training. Their findings indicate significantly favorable results for individuals with RR genotypes in the torque curves.

Gentil et al. (29) submitted 141 men to 11 wks of resistance training in order to verify the responses between the variations in strength and gains in muscle mass and the R577X polymorphism. The results of the muscle strength phenotype did not show differences in pre- and post-training in resistance exercises. However, the subjects carrying the R allele showed gains in muscle mass in knee extensors in response to training. These data reflect that, even without significantly influencing muscle strength, the presence of the R allele may somehow modulate important responses to muscle hypertrophy. Regarding the response to strength training associated with the genetic polymorphism of non-physical activity in women with XX genotype, Clarkson et al. (14) indicated that they had lower values both in absolute and relative strength in the 1-MR tests when compared with the RR genotype after the training program.

In an attempt to find a relationship between the ACTN3 genotype and the type of muscle fibers in short or long-distance skaters and control individuals, Ahmetov et al. (3) found that the frequency of ACTN3 XX genotype was significantly lower in skaters when compared to controls (2.6 vs. 14.5%; P=0.034). On the other hand, the polymorphism of the ACTN3 gene was found to be higher in individuals with type I fibers. These data corroborate with other studies that suggest the ACTN3 gene can modulate significant responses towards the control of type II fibers formation, since those deficient of α-actinin-3 were diagnosed with high percentage of type I fibers.

A review of 23 studies about ACTN3 and sports performance (36) has shown a higher probability of performance in strength and power events for R alleles. This finding supports the general consistency of the literature regarding the association between the ACTN3 genotype and athletic performance in sports with such characteristics. The association of ACTN3 and R577X variation with performance is undoubtedly the strongest association currently found. The study highlights that most consistent associations between ACTN3 genotype and performance were observed in athletes. These associations were also reviewed by Eynon et al. (22) who found a higher prevalence of RR genotype among strength and power athletes.

On the other hand, Scott et al. (50) did not find differences in the frequency of genotype in sprinters and non-athlete individuals. In their study, Jamaican elite sprinters (JA) and North American elite sprinters (NA) were compared to non-athletic Jamaicans (NAJ) and non-athletic North Americans (NANA). Low frequencies of genotype XX were found in all groups, with frequencies of 3% for JA, 2% for NA, 2% for NANA, and 4% for NAJ. The research indicates that the athletes were not significantly different from the control individuals for the frequency of genotype XX. In addition, both control groups showed a genotype XX frequency well below the population (~18%), which suggests that the ethnic group of the population may be seen as an important factor in the genetic ACTN3 polymorphism research.

João and colleagues (33) analyzed the frequency of genotype and the ACTN3 allele in order to build a profile for gymnasts. The results indicated a predominance of the RX genotype and the R allele, which may provide a genetic advantage for muscle strength and power levels that facilitate competitive performance and success in gymnastics (33). The expression of α-actinin-3 protein is almost exclusively restricted to fast fibers, glycolytic metabolic pathways, to type 2X fibers that are in charge of maximum production of muscular power (42). In addition, the "R" allele carriers present a higher speed of maximum power production and greater rigidity in type IIa / IIx fibers when compared to genotype XX (10).

The findings presented in this relatively brief review suggest that the presence of the α-actinin-3 isoform is beneficial to strength and power sports, while its absence seems to benefit endurance athletes.

The Angiotensin Converting Enzyme Gene and Its Relationship with Physical exercise and Sports Performance

In an attempt to identify a relationship between ACE polymorphism and echocardiographic data of children of hypertensive patients compared with young children of normotensive individuals, Franken et al. (27) studied 80 normotensive youngsters who were split into 2 groups: (a) 40 normotensive children of normotensive parents (NP); and (b) 40 normotensive children of hypertensive parents (HP). The results indicate that HP group had a greater thickness of the inter-ventricular septum. However, no differences were found between the groups with regards to the genotype of the ACE gene, as the genotyping of the HP group (D/D 42.5%, I/D 37.5%, I/I 20%), and of the NP (D/D 37.5%, I/D 32.5%, I/I 30%) was statistically quite similar. Therefore, they concluded that, although there was a significant difference in inter-ventricular septum thickness between the groups, there was no correlation of the data with the ACE gene polymorphism when analyzing the genotypes and the alleles separately.

A study seeking to identify the same association was carried out by Napoles et al. (45). They studied the I/D polymorphism of ACE in Cuban hypertensive patients. In this study, 243 hypertensive and 407 normotensive individuals were matched by age, sex, and ethnicity in the city of Havana. The polymorphism was determined by the polymerase chain reaction (PCR). The absolute results of the genotyping showed significant differences only in black women, with the D allele being the most frequent in hypertensive patients when compared to normotensive individuals (0.58 and 0.54, respectively). They concluded that the I/D polymorphism of ACE is not associated with hypertension in the Cuban multiethnic sample.

Dehnert et al. (18) conducted a study with 83 mountaineers, who were evaluated after an overnight stay at an altitude of 4559 m. The objective was to correlate acute mountain sickness and pulmonary edema with the genotype DD of the ACE gene, but there was no correlation between the analyzed variables. Therefore, the authors concluded that the I/D polymorphism of ACE was not related to both conditions in athletes.

Freitas and colleagues (28) evaluated the influence of six polymorphisms present in RAS on the development of hypertensive disorders in 150 people from the city of Santa Isabel do Rio Negro, Brazil, who were split into the normotensive group with 78 subjects and the hypertensive group with 82 subjects. With regard to the ACE I gene, the following genotypic distribution was observed: II = 67%, ID = 25%, and DD = 8%. In addition, in the hypertensive group, a higher increase in systolic blood pressure was observed in those with D allele when compared with the subjects II and ID.

Despite the relationship of the D allele with hypertensive frames, it can also be associated with significant increases in strength that may represent advantages in strength and power events (56). This relationship can denote that the D allele takes part on the mechanisms of cell differentiation. Zhang et al. (62) corroborates this point by stating that, in subjects with genotype II, the incidence of type I fibers is 59.4%, 15.2% for type IIa, and 25.5% for type IIb; whereas, DD individuals present 19.6% of type I fibers, 29.6% of type IIa fibers, and 50.9% of type IIb fibers. An inverse relationship between the DD genotype with the type I fibers and the genotype II with the type II fibers is then perceived. These findings may explain some results found in association studies, in addition to suggesting that the DD genotype is related to the muscle strength phenotype, since subjects with this variation had a higher proportion of glycolytic fibers. However, the association between the allele I and endurance events may be a consequence of a higher proportion of contraction fibers in subjects with genotype II.

In order to test the hypothesis that the D allele modulates physical performance, Cam et al. (12) analyzed the results of 88 Turkish non-athletes after performing sprints (60 m) and moderate distance runs (2000 m). The authors classified the participants according to race performance (long, medium, and short), and noticed that the subjects with DD genotype had a better performance in the medium distance runs. However, in the sprints, no difference among the genotypes was observed. These results indicate that the D allele may contribute towards important physiological responses in aerobic exercise performed by non-athletes.

In another investigation using non-athletes, Chiu et al. (13) tested the strength of manual grip, power, and speed of Thai teenagers. The results of the tests showed a positive association between the DD genotype and the manual grip strength, but no differences were observed in the other tests. In contrast to the D allele, the Ma et al. (36) study indicates that the I allele may modulate the performance in endurance events.

Montgomery et al. (44) were able to confirm this information by testing extreme resistance athletes who frequently climb altitudes above 7000 m. The authors identified that about 50% of the sample presented genotype II, while only 10% were diagnosed as DD genotypes. The same authors conducted a 10-wk general training protocol to assess elbow flexor muscle resistance responses in 123 UK recruits, and only 78 of them completed the protocol. The sample was tested before and after training, and the results showed significant increases in the execution time of recruits with genotype II (79.4 ± 25.2 sec) when compared to DD (7.1 ± 14.9 sec).

Williams et al. (57) checked the relationship between the I/D polymorphism of ACE and the mechanical muscular efficiency of 58 Caucasian men who were engaged in aerobic training. The results indicated a significant difference between genotype II and DD ($P<0.025$). Thus, an increase in mechanical efficiency of 8.26% for the insertion homozygote could be observed; whereas, in homozygous deletion subjects there was no apparent improvement. These responses may indicate the possibility of genotype-dependent adaptations in endurance exercises.

Wang et al. (55) analyzed the performance of 326 East Asian swimmers (166 short-distance swimmers (≤100 m) and 160 mid-range swimmers (200-400) by comparing them to 200 European or American swimmers (identified as Caucasians who swam 130 short or mid-distance (≤400 m) and 70 long distance (>400 m). Differences were reflected in genotype frequency and association with performance in different populations. The Asian athletes presented the following genotypic frequency for short or medium distances, respectively, DD = 9.6% and 7.5%; ID = 39.4% and 49.4%; II = 55.4% and 43.1%. However, the Caucasian swimmers presented the following frequency for short distances (DD = 40.7%, ID = 39.8%, and II = 19.5%) and long distances (DD = 28.8, ID = 47 %, and II = 24.2%). These data suggest that the genotypic frequency of ACE in Asians is different from the Caucasians, and point out inversely proportional frequencies among the populations studied, since among the short distance Asian athletes the frequency of II is very evident. For the Caucasians, the DD genotype was strongly associated with shorter distances. These findings raise two important points. The first one is there may be other genetic variations in Asian populations that confer advantage on shorter events, but have not been identified. Second, the fact is that specific training may have conferred an adaptive advantage on the swimmers.

In a similar study, Massidda et al. (39) checked the relationship between the ACE gene and the performance of 17 Italian gymnasts, 12 sprinters and mid-distance runners, and 30 football players. Their results indicate the following: gymnasts (53% DD, 38% ID, and 9% II); runners (50% DD, and 50% ID); and footballers (60% DD, 30% ID, and 10% II). Despite this apparently high incidence of the DD genotype in relation to II, the allelic distributions did not show a significant difference between the I and D alleles. Therefore, the authors concluded that there was no association between ACE I/D polymorphism and athletic performance.

The research findings suggest that the angiotensin converting enzyme gene may be an important genetic factor for improving sports performance in aerobic athletes. But, some limitations in studies with polymorphisms should be considered, such as: (a) control group selection; (b) reduced (small) samples; and (c) heterogeneity of the studied population, which could influence the phenotypic trait of the evaluated ones. Also, the physiological changes associated with angiotensin converting enzyme gene insertion polymorphism were observed mainly in highly trained athletes. This suggests the possible influence of aerobic physical training on the optimization of the physiological responses in individuals with ECA gene polymorphisms.

Regarding the angiotensin-converting enzyme activity in strength gains, the studies indicate that individuals who present the D allele of the angiotensin-converting enzyme show a greater genetic predisposition to increase muscle strength after the strength training season, when compared to individuals who present alleles II and ID. This finding may be related to the improvement of the individuals' neural adaptations and the greater muscle hypertrophy.

Dermatoglyphics Relationship with Sports Performance

Dermatoglyphics is a term that has been used since the 19th century as a tool for biological identification in various situations, such as forensic investigation, the identification of some pathologies and, more recently, in association with phenotypes that confer advantage in athletic performance (1,25,41).

The dermatoglyphs (or dermopapillary ridges) are formed between the 12th- and 24th-wk of intrauterine life along with the blastogenic extract of the nervous system in the ectoderm and become immutable after childbirth, except in pathological conditions (38). The dermatoglyphic configurations, once printed on a surface, are then called digital fingerprints (17), which are then analyzed qualitatively and quantitatively. Qualitatively refers to the characteristic of the configuration (A, Lr or Lu, and W). Quantitatively is represented by the Ridge Count (RC) and by the Total Ridge Count (TRC). From the qualitative characteristics, there is another quantitative variable called "Delta Index" (D10) that corresponds to the number of deltas present in the fingerprint. Arc (A) is the configuration that does not have any delta; Loop (L) is the configuration that presents one delta, and Whorl (W) is the configuration that usually presents two deltas, which is represented successively according to the corresponding evaluation (0, 1, and 2), which means someone can present a maximum of 20 and minimum of 0, The simplest configuration is the Arch and the most complicated is the Whorl. Then, D10 is calculated by the equation: $D10 = \Sigma L + 2 * \Sigma W$ (1). This quantitative value of genetic markers may reveal a predisposition for potentiated basic physical qualities, such as motor coordination, aerobic resistance, speed, and power (16).

Abramova and colleagues (2) characterize dermatoglyphics as a simple and efficient method for reading the genetic potential, regarding the abilities and possibilities of young athletes. Fernandes Filho (24) adds that the analysis of fingerprints allows a more adequate choosing and specialization in sport with the expectation of optimizing individual talents. The association studies between dermatoglyphics and sports performance developed in Brazil by Fernandes Filho (24) indicate that low values for D10 and TRC are related to higher strength gains, but with a low coordinative capacity. On the other hand, the same author states that the high values for D10 and TRC, represented by the high incidence of L and W, are associated with predominately aerobic sports, which corroborates with the studies of the Russian researchers (2). They state that the analysis of the fingerprints of high performance athletes from several different groups of sport and from several positions reveals certain tendencies in the correlations of the integral indexes of the specific fingerprints for the sports. In fact, sports that require power and short time duration have low values for D10, an increased number of A and L, and a decreased number of W and TRC. Conversely, high values for D10, the absence of A, increases in W incidences, and increases in TRC characterize sports that require aerobic endurance and coordination as well as differences in speed resistance groups.

Interestingly, this hypothesis by Abramova et al. (2) has been tested by several researchers (15,19,24,48) who have not only confirmed the relationship of this biological marker to sports performance, but have also advised people regarding the practice of physical exercises in a safe way that allows for an emphasis on preventive health and satisfactory results. An example is the study with high performance athletes by Medina (40), who analyzed the dermatoglyphics characteristics of the Brazilian adult national volleyball 2000 team (22 players). The results showed a low incidence of A (0.1) in relation to L (6.5) and W (3.4). For the digital formulas, the prevalences were L≥W (40.9%), W≥L (27.3%), and 10L (22.7%). A few years later, Fonseca et al. (26) also evaluated 28 athletes of the Brazilian volleyball team and found the following results for the fingerprints: A (11%), L (60%), and W (29%). Regarding the digital formulas, they found ALW = 28.6%, L>W = 28.6%, and W>L = 21.4%. Also, Borin et al. (7) evaluated the Brazilian adult basketball team, and found very similar results to the studies by Medina (40) and Fonseca et al. (26).

Zary et al. (61) also evaluated 38 volleyball players from 3 different Brazilian national teams: adults (n = 14), junior (n = 12), and juvenile (n = 12). The prevalence of the digital patterns in the adult team was 25% for W>L, 25% for L>W, 25% for W=L, 8.33% for 10L, 8.33% for ALW, and 8.33% for AL. The prevalence for the junior team was 27.27% for W>L, 18.18% for

L>W, 27.27% for 10L, and 27.27% for ALW. The prevalence for the juvenile team was 16.7% for AL, 22.2% for ALW, 38.9% for L>W, 11.1% for W>L, 5.6% for 10W, and 5.6% for L=W. These data suggest a higher predisposition for explosive strength, motor coordination and speed resistance for the adult group. Given the dynamics of volleyball and its physical requirement, the identification of the genetic predisposition from the collection of the fingerprints may help contribute to the identification of the characteristics of the players and guide them in the development of physical training to enhance their physical capacities.

De Carvalho et al. (17) reported on the profile of endurance runners from the city of Rio de Janeiro, Brazil. Their research found that the identification of the configurations indicated that L appeared more frequently (7.83 ± 1.59), which was followed by W (1.83 ± 1.70) and A (0.33 ± 0.65). Given that endurance sports require a high level of cardiorespiratory fitness and the understanding that this physical quality is related to genetic variations, the authors' findings confirm the hypothesis that higher values for D10 and TRC may influence the development of aerobic resistance and sports performance in endurance sports. Similar work was carried out by Diaz and Espinoza (19) who reported on the relationships between dermatoglyphic patterns and physical fitness for beginners and specialized athletes in Chile. They found that male sprinters had "L" values of 18.5 ± 24.0, “A” values of 1.0 ± 0.8, “W” values of 3.17 ± 4.6, and TRC values of 72.83 ± 13.9. For the long-distance runners, the results were "L" = 6.0 ± 2.8, "A" = 1.57 ± 3.5, "W" = 2.43 ± 1.6, and “TRC” = 93.93 ± 47.3, which indicate a strong association between their physical fitness and the genetic profile.

Montenegro et al. (43) developed a study with the purpose to associate dermatoglyphics with the molecular marker ACTN3 and sports phenotypes. Their tests were applied to evaluate general strength, speed, power, and aerobic endurance of 82 young subjects from the state of Paraíba, Brazil. The results of the dermatoglyphic evaluation indicated that the highest D10 and TRC indexes were found in the subjects whose sport had a predominance of aerobic resistance, while the lowest values were found in athletes of muscular power and general strength sports. With regards to the frequency of the ACTN3 genotype, no general strength athlete presented the genotype XX, while all power sports subjects were classified as homozygotes for the X allele. In addition, curiously, no aerobic predominance athlete was identified as deficient for α-actinin-3. While there is the need for more research to analyze to verify the degree of association between these genetic markers and aerobic sports, the dermatoglyphics show association with ACTN3 to verify general strength in the Montenegro et al. (43) study.

Hernandez and colleagues (30) evaluated the dermatoglyphic characteristics of 20 Chilean football players. The prevalence of "L" configuration was observed in more than half of the sample (55%), followed by "W" (43%), and "A" (2%). For the TRC, 146 ± 37.42 was found, and for the D10, 14.6 ± 2.50. These results suggest relationship between the dermatoglyphic characteristics and the physical qualities potentiated by the high D10 and high TRC that characterized these athletes as having good coordination and high resistance levels.

In a recent study with national Paralympics Brazilian canoeists, Sousa and colleagues (53) analyzed the dermatoglyphics and the manual gripping force of the finalist paracanoeists of the National championship. The results demonstrated a prevalence of L over W and A (75%, 20% and 5%, respectively), and an increase in the D10 (14.5 ± 2.3) in addition to a high TRC (159.0 ± 49.8). The results also showed a high level of manual grip strength among athletes

(40.1 ± 17.6). The results of this study also classified dermatoglyphics as a good genetic marker, capable of predicting the sports orientation of the subjects as well as the direction of their training.

For Pavel and Fernandes Filho (48), the increase in the level of indexes and sports results raises the need to optimize the sports preparation and, in such a context, dermatoglyphics is potentially a very useful tool in indentifying and guiding athletes. By prior identification of the athlete's genetic characteristics and by including dermatoglyphics in the sports field, it is possible to study and understand the individual differences and their potentialities regarding the specific sports and the genetic limitations that may impair success and the ability to improve in sports training (51). Linhares et al. (35) also add that the dermatoglyphic method applied to sports allows for a detailed planning of individualized training programs, thus allowing for a satisfactory and successful development of the athlete, in order to achieve the maximum performance possible.

The research literature (1,11,24,48) suggests that it is important to investigate the role of dermatoglyphic characteristics at several levels of sports qualification. Thus, there are indications that there may be a positive association between dermatoglyphics and R577X polymorphisms of the ACTN3 gene and I/D of the ACE gene, which may allow for a rich field of investigations as well as the confirmation of dermatoglyphics as a powerful tool for identification of such genetic alterations.

CONCLUSIONS

Undoubtedly, the data collected in the present study are of scientific relevance, but they are not conclusive, since the consequences of some genetic variations in humans still need to be better clarified. It is important to recognize that the investigations with the ACTN3 and ACE genes as well as the use of dermatoglyphics have shown correlation with sports performance. Thus, it is worth noting that genetic analysis, physical effort, and the specifics of different sports modalities require a great deal of attention, especially since genetic predisposition is not always reflected in satisfactory results (given that it requires a lot of resource and commitment in technical, tactical, physical, and psychological matters). We suggest further investigations correlating other genes with those already investigated, and the dermatoglyphic markers with athletes and non-athletes with the expectation to answer the numerous recurring questions of genetic modulation in athletic performance. Also, we believe it is appropriate to recommend that dermatoglyphics, classified as an inexpensive, easy, and quick applicability approach, can be an enormous potential tool in the investigations of the correlations between the polymorphisms and athletic performance.

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