Journal of Science and Medicine in Sport xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Review

Nine genetic polymorphisms associated with power athlete status – A Meta-Analysis

Jan Weyerstraß[a,*], Kelly Stewart[a], Anke Wesselius[a], Maurice Zeegers[b]

[a] Department of Complex Genetics, School of Nutrition and Translational Research in Metabolism (NUTRIM), Maastricht University Medical Centre, The Netherlands
[b] Department of Complex Genetics, School of Nutrition and Translational Research in Metabolism (NUTRIM), CAPHRI School for Public Health and Primary Care, Maastricht University Medical Centre, The Netherlands

ARTICLE INFO

Article history:
Received 2 December 2016
Received in revised form 4 June 2017
Accepted 13 June 2017
Available online xxx

Keywords:
Muscular power
Single nucleotide polymorphism
Candidate gene study
Cohort
Case-control

ABSTRACT

Objectives: In this study the association between genetic polymorphisms and power athlete status with possible interference by race and sex was investigated to identify genetic variants favourable for becoming a power athlete.
Design: This meta-analysis included both, case-control and Cohort studies.
Methods: Databases of PubMed and Web of Science were searched for studies reporting on genetic polymorphisms associated with the status of being a power athlete. Thirty-five articles published between 2008 and 2016 were identified as eligible including a total number of 5834 power athletes and 14,018 controls. A series of meta-analyses were conducted for each of the identified genetic polymorphisms associated with power athlete status. Odds ratios (ORs) based on the allele and genotype frequency with corresponding 95% confidence intervals (95%CI) were calculated per genetic variant. Heterogeneity of the studies was addressed by Chi-square based Q-statistics at 5% significance level and a fixed or random effects model was used in absence or presence of heterogeneity respectively. Stratified analyses were conducted by race and sex to explore potential sources of heterogeneity.
Results: Significant associations were found for the genetic polymorphisms in the *ACE* (rs4363, rs1799752), *ACTN3* (rs1815739), *AGT* (rs699), *IL6-174* (rs1800795), *MnSOD* (rs1799725), *NOS3* (rs1799983, rs2070744) and *SOD2* (rs4880) genes.
Conclusions: Nine genetic polymorphisms have been identified in the meta-analyses to have a significant association with the status of being a power athlete. Nevertheless, more research on the investigated genes needs to be done to draw comprehensive conclusions.

1. Introduction

Typical power related sports can involve a short movement as sprinting and throwing but also a series of the same or different power movements over time, for example rowing.[1,2] The development of high muscular power can be seen as the main goal of any power athlete for achieving the maximum performance in their sport. Muscular power is an important component of fitness for power athletes as it is needed in any movement of a power related sport, requiring a well-trained muscular system.[3] This component refers to the ability to exert a maximal force at a given period of time, also equivalent to the energy output per unit of time or the rate of work.[4] Muscular power is mainly expressed as the power output, which is determined by physiological factors like muscle fiber size, length, muscle fiber type and the muscle fiber maximum contraction velocity (Vmax) with the athlete's relative proportions of the two muscle fiber types as one of the most important factors.[5] Literature suggests that the proportion of type I and type II muscle fibers is almost equal in healthy sedentary controls,[6] while power athletes of higher competitive level were estimated to have up to 80% type II muscle fibers[7] indicating that a high proportion of type II muscle fibers might be beneficial for power related sports. Type II muscle fibers can be divided in: a) oxidative IIa and b) glycolytic IIx muscle fibers. While IIx muscle fibers fatigue more quickly than IIa, they produce the highest force and are, therefore, most useful for very short explosive movements.[5] Muscle fiber size, shape and proportion of different fiber types are partially determined by the athlete's genotype, meaning that favorable genotypes for power related sports can be identified and used to optimize training programmes. In 2007, De Moor et al.[8]

* Corresponding author.
E-mail address: Jan.Weyerstrass@uni-wh.de (J. Weyerstraß).

http://dx.doi.org/10.1016/j.jsams.2017.06.012
1440-2440/

estimated the genetic predisposition of athletic performance to be greater than 60% and only one third being due to environmental components such as training, nutrition and technological aids,[9,10] underlying the importance of sports genomics for researchers, athletes and coaches.[11] To date, several genes associated with power athlete performance have already been suggested.[12,13] One example of a commonly researched genetic variant in relation to the status of being a power athlete is the single nucleotide polymorphism (SNP) rs1815739, which alters the normal C-nucleotide in a T-nucleotide, in the *ACTN3* gene. The *ACTN3* gene encodes for the α-Actinin-3 protein, an actin-binding protein that plays a role in the human skeletal muscle. This protein is expressed in the type II muscle fibers where it helps to keep the myofibrillar actin filaments attached to each other.[14] A non-sense mutation results in a dysfunctional version of the protein, leading to a deficiency of the α-Actinin-3 protein which is substituted by alpha-actinin-2.[15] This deficiency slows metabolic and physiological properties of fast fibres resulting to a shift toward increased oxidative metabolism in fast muscle fibres and thereby decreasing the speed in which these muscle fibers can generate force.[16] Therefore, it is not surprising that MacArthur et al.[15] and Yang et al.[17] observed a higher frequency of the CC (RR) genotype at this SNP in sprint athletes, a typical power sport, compared to healthy sedentary controls. Many other genes have been linked to power athlete status, i.e. *ACE*, *ADRB1*, *ADRB2*, *ADRB3*, *AGT*, *CNTFR*, *FTO*, *IGF1*, *IGF-IR*, *IL6-174*, *GDF-8*, *GNB3*, *MCT1*, *MnSOD*, *NOS3*, *NRF-2*, *SOD2*.<

Although there is a lot of existing literature on genetic polymorphisms associated with power athlete status, studies generally investigate no more than one or two specific genetic variants or do not include a meta-analysis.[18–20] Identifying genetic variants associated with power athlete status is relevant for researchers, athletes and the coaching team to optimize the training process. This genetic knowledge may help athletes to develop their athletic potential most optimally. Therefore, the aim of this meta-analysis is to quantify the association between genetic polymorphisms and the status of being a power athlete.

2. Methods

2.1. Literature identification

Databases of PubMed and Web of Science were searched for eligible studies assessing genetic polymorphisms related to the status of being a power athlete during the period from the 2th of April 2016 until the 10th of August 2016.

Included search terms consisted of the names of several genetic polymorphisms, SNPs and "genetic polymorphism" in combination with "muscular power" and "power". Furthermore, additional studies were identified through cross-referencing of relevant reviews obtained in the search. No restriction was used with regard to the language or the date of publication.

2.2. Inclusion and exclusion criteria

Articles were considered eligible if they assessed genetic polymorphisms associated with the status of being a power athlete, which was defined as athletes competing at higher national and/or international competitive level, with the sport being identified as a power sport by the authors of each study. Included power athletes were sprinters, jumpers, throwers, track athletes, swimmers, rowers, short distance speed skaters, ice hockey players, rugby players, bodybuilders, power lifters and weightlifters. Articles using animals, diseased participants or review articles were excluded.

2.3. Data extraction

For all articles, the following information of the study was extracted: author and year, journal, country of the study, objective of the study, study design, total number of athletes and controls, type of athletes and controls, race and sex of participants, researched gene(s), reported subpopulations within the study population, major allele and the preferential genotype for power athlete status (reference group), genotype and allele frequencies among power athletes and controls and for each of the subgroups.

2.4. Statistical analysis

A series of meta-analyses were conducted for each of the identified genetic polymorphisms associated with power athlete status. The strength of association of the genetic polymorphisms with power athlete status was estimated by calculating odds ratios (ORs) with corresponding 95% confidence intervals (95%CI) per genetic variant, based on the allele and genotype frequencies. Heterogeneity of the studies was addressed by Chi-square based Q-statistics. A random effects model was used in case of statistically significant heterogeneity, while a fixed effects model was used otherwise. Stratified analyses were conducted by race and sex to explore potential sources of heterogeneity in the studies and create insight into the associations of each genetic variant on power athlete status under influence of the stratified factors. The statistical analyses were done in Stata 14 (Statacorp LP) with significance levels of 5%, which represents a p-value of <0.05.

3. Results

A total of 4728 articles were identified through the search in PubMed and Web of Science (Fig. 1). After deduplication, 2626 articles were scanned based on title and abstract, of which 2534 articles were excluded. From the 92 remaining articles, another 61 articles were excluded after full text selection due to the following reasons: used athletes were not clearly defined as power athletes or not of higher competitive level, a control group was missing, or allele and genotype frequencies were not reported. Four usable articles were identified through cross-referencing resulting in a final number of 35 articles published between 2008 and 2016.

Table 1 shows the characteristics of the 36 included studies regarding author, year, country, race as well as the total of investigated genes and the total of included athletes and controls.

Table 2 shows the results of the meta-analyses of the association between the genetic polymorphisms of the *ACE* (rs4363, rs1799752), *ACTN3* (rs1815739), *AGT* (rs699), *FTO* (rs9939609), *IL6-174* (rs1800795), *GNB3* (rs5443), *NOS3* (rs2070744) gene and power athlete status for all genes with two or more studies per SNP. In this table only the overall analyses for each gene are presented. The subgroup analyses for each gene can be found in Table 3. With regard to the SNP *ACE* rs4363, athletes carrying the AG genotype had a significantly 1.69 (95%CI = 1.12; 2.56) times greater chance of becoming a power athlete compared to athletes carrying the preferential genotype for power athlete status (AA). In the subgroup analysis by race, having the AG genotype yielded a significantly 2.18 (95%CI = 1.19; 3.99) lower chance of becoming a power athlete among the US African American group, but not among the Jamaican subgroup. At the SNP *ACE* rs1799752, an insertion (ID genotype) resulted in a significant association with power athlete status (OR = 0.64; 95%CI = 0.41; 0.99) compared to the preferential genotype for power athlete status (DD, no insertions) in Caucasians. Furthermore the ID genotype yielded significance among a European population (OR = 0.46; 95%CI = 0.25; 0.86) and

Please cite this article in press as: Weyerstraß J, et al. Nine genetic polymorphisms associated with power athlete status – A Meta-Analysis. *J Sci Med Sport* (2017), http://dx.doi.org/10.1016/j.jsams.2017.06.012

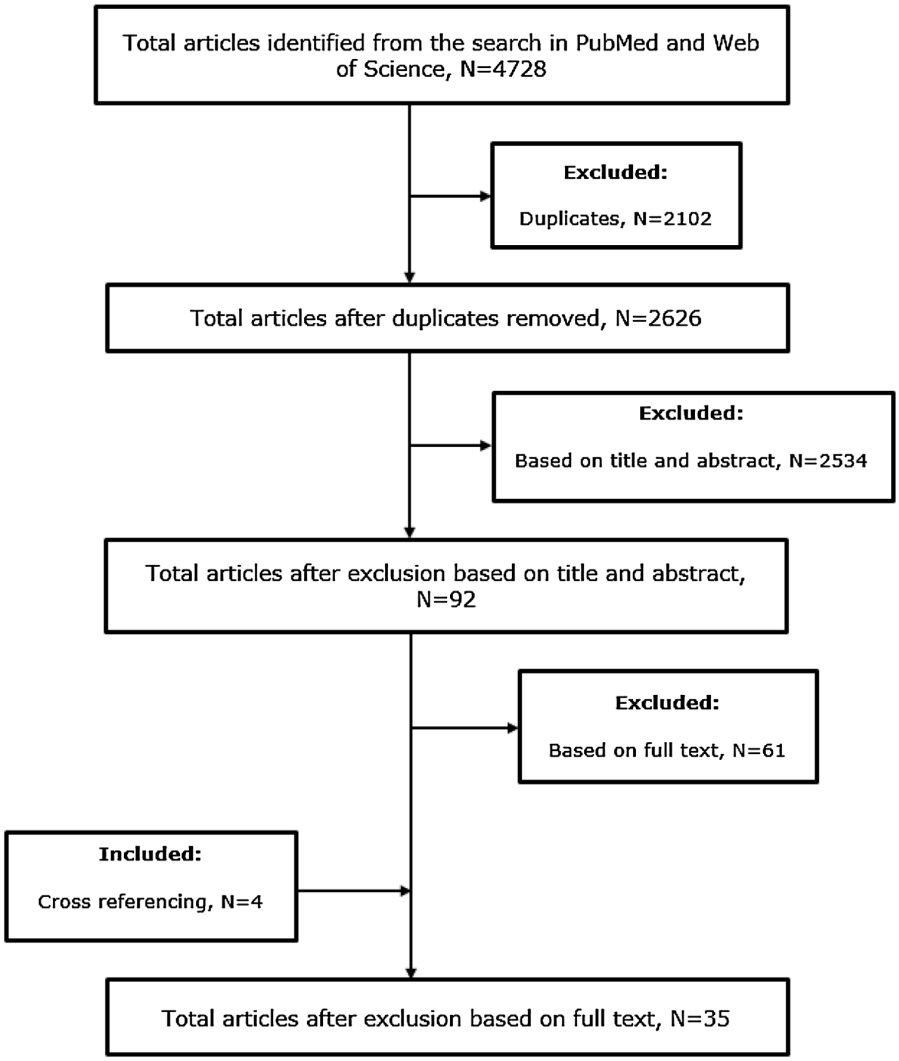

Fig. 1. Flow Diagram of study design.

US African Americans (OR = 0.80; 95%CI = 0.70; 0.91). With regard to SNP rs1815739 of the *ACTN3* gene, carriers of the T allele had a 0.80 (95%CI = 0.70; 0.91) lower chance of becoming a power athlete compared to carriers of the C allele. Furthermore having the CT genotype resulted in a 0.58 (95%CI = 0.48; 0.70) times lower chance of becoming a power athlete when compared to the preferential genotype for power athlete status (CC). In the subgroup analysis by race, significance was observed for having the CT genotype compared to the preferential genotype for power athlete status (CC) among the Caucasian group (OR = 0.84; 95%CI = 0.42; 0.67). In Asians, athletes having the CT genotype were significantly 0.70 (95%CI = 0.52; 0.95) times less likely to become a power athlete compared to the preferential genotype for power athlete status (CC). Subgroup analysis by sex yielded significance for T allele carriage and having the TT genotype in both groups: males and females together and males only (see Table 2 for further details). Additionally, a significant association with power athlete status (OR = 0.44; 95%CI = 0.27; 0.84) was found for having the TT genotype compared to the preferential genotype for power athlete status (CC) in Russians. With regard to SNP rs699 of the *AGT* gene, athletes carrying the C allele had a significantly 1.59 (95%CI = 1.15; 2.20) times greater chance of becoming a power athletes compared to athletes carrying the T allele. Furthermore, having the CC genotype resulted in a significantly 2.54 (95%CI = 1.69; 3.82) times greater chance to become a power athlete compared to the preferential genotype for power athlete status (TT). In the subgroup analysis by sex, significance was observed for athletes carrying the C allele (OR = 1.863; 95%CI = 1.06; 3.27) compared to athletes carrying the T allele and athletes having the CC genotype (OR = 2.89; 95%CI = 1.64; 5.07) compared to athletes having the TT genotype in males and females together. In the male subgroup, having the CC genotype resulted in a significantly 2.20 (95%CI = 1.21; 3.99) times lower chance of becoming a power athlete compared to having the preferential genotype for power athlete status (TT).

With regard to SNP rs1800795 of the *IL6-174* gene, athletes carrying the C allele were significantly 0.67 (95%CI = 0.47; 0.94) times less likely to become a power athlete compared to athletes carrying the G allele. Furthermore, having the GC genotype had a 0.51 (95% = 0.35; 0.74) lower chance of becoming a power athlete compared to the preferential genotype for power athlete status (GG). In the subgroup analysis by sex, significant associations with power athlete status were observed for C allele carriage (OR = 0.58; 95% = 0.41; 0.82) compared to G allele carriage, the CC genotype (OR = 0.53; 95% = 0.33; 0.83) and the CG genotype (OR = 0.43;

Please cite this article in press as: Weyerstraß J, et al. Nine genetic polymorphisms associated with power athlete status – A Meta-Analysis. *J Sci Med Sport* (2017), http://dx.doi.org/10.1016/j.jsams.2017.06.012

Table 1
Descriptive table of included studies.

Study	Country of study[a]	Race	Name genes (rs number)	Total athletes	Total controls
Ahmetov et al.[12]	RU, PL	Caucasian	SOD2 CT (rs4880)	321	917
Bell et al.[48]	WAL, UK	European	ACTN3 CT (rs1815739)	102	110
Ben-Zaken et al.[56]	IL	Caucasian	IGF1 CT (rs35767)	160	159
Ben-Zaken et al.[35,57]	IL	Caucasian	IGF-IR AC(rs1464430)	87	159
Ben-Zaken et al.[61]	IL	Caucasian	MnSOD CT (rs1799725)	65	128
Ben-Zaken et al.[61]	IL	Caucasian	MCT1 AT (rs1049434)	74	240
Cieszczyk et al.[14]	PL	Caucasian	ACTN3 CT (rs1815739)	158	254
Cieszczyk et al.[44]	PL	Caucasian	ACTN3 CT (rs1815739)	80	204
Costa et al.[41]	PT	European	ACE ID (rs1799752)	25	100
Druzhevskaya et al.[49]	RU	Caucasian	ACTN3 CT (rs1815739)	486	1197
Eider et al.[32]	PL	Caucasian	IL6-174 GC (rs1800795)	158	254
Eider et al.[36]	PL	Caucasian	NOS3 GT (rs1799983)	116	191
Eider et al.[32,42]	PL	Caucasian	ACE ID (rs1799752)	100	354
Eynon et al.[46]	ES, PL, RU	Caucasian	ACTN3 CT (rs1815739)	349	808
Eynon et al.[31,58,62]	ES, PL, RU	Caucasian	FTO	285	1416
Eynon et al.[31,58,62]	ES	Caucasian	NRF-2 AC, AG, CT (rs12594956, rs7181866, rs8031031)	114	330
Eynon et al.[34]	IL, ES	Caucasian	IL6-174 GC (rs1800795)	81	205
Eynon et al.[45]	ES, PL, RU	Caucasian	ACTN3 CT (rs1815739)	379	568
Garatachea et al.[50]	ES	Caucasian	ACTN3 CT (rs1815739)	100	283
Gomez-Gallego et al.[28,37]	ES	Caucasian	AGT CT (rs699)	63	119
Gomez-Gallego et al.[28,37]	ES	Caucasian	NOS3 TC (rs2070744)	100	100
Hong et al.[51]	KR	Caucasian	ACTN3 CT (rs1815739)	84	361
Kikuchi et al.[52]	JP	Asian	ACTN3 CT (rs1815739)	627	810
Miyamoto-Mikami et al.[55]	JP	Asian	CNTFR CT (rs3745672)	211	814
Papadimitriou et al.[47]	GR	Caucasian	ACE ID (rs1799752)	73	181
Papadimitriou et al.[43]	GR	Caucasian	ACTN3 CT (rs1815739)	73	181
Ruiz et al.[29]	ES	Caucasian	ACE ID (rs1799752), ACTN3 CT (rs1815739), AGT CT (rs699), IL6-174 GC (rs1800795), GDF-8 AT (rs1805086), NOS3 TC (rs2070744)	53	100
Ruiz et al.[53]	ES	Caucasian	ACTN3 CT (rs1815739)	119	343
Ruiz et al.[29,33]	ES	Caucasian	IL6-174 GC (rs1800795)	53	100
Ruiz et al.[60]	ES, IL	Caucasian	GNB3 CT (rs5443)	134	340
Santiago et al.[54]	ES	Caucasian	ADRB1 AG (rs1801253), ADRB2 GA, GC (rs1042713, rs1042714), ADRB3 TA (rs4994)	53	100
Sawczuk et al.[59]	PL	Caucasian	GNB3 CT (rs5443)	100	354
Scott et al.[21]	JAM, US	African	ACE AG (rs4363)	644	1458
Yang et al.[17]	AU	Caucasian	ACTN3 CT (rs1815739)	107	436
Zarebska et al.[30]	PL	Caucasian	AGT CT (rs699)	100	344

[a] This is the country, where the study took place; Abbreviations used were: AU = Australia, ES = Spain, GR = Greece, IL = Israel, JAM = Jamaica, JP = Japan, KR = Korea, PL = Poland, PT = Portugal, RU = Russia, UK = United Kingdom, US = United States; WAL = Wales.

Table 2
Meta-analyses of the association between the genetic polymorphisms of the investigated genes and power athlete status with two or more studies per SNP.

Gene	Subgroup analysis	No. of studies	Major allele	Wildtype	Allele based OR[a] (95%CI)	HMGT based OR[b] (95%CI)	HTGT based OR[c] (95%CI)
ACE AG (rs4363)	Overall	2	A	AA	1.14 (0.77; 1.70)	1.10 (0.66; 1.84)	**1.69 (1.12; 2.56)**
ACE ID (rs1799752)	Overall	6	D	DD	0.83 (0.62; 1.11)	0.73 (0.45; 1.18)	0.84 (0.59; 1.20)
ACTN3 CT (*rs1815739*)	Overall	19	C	CC	**0.79 (0.69; 0.91)**	**0.58 (0.47; 0.71)**	**0.86 (0.75; 0.98)**
AGT CT (rs699)	Overall	3	T	TT	**1.59 (1.15; 2.20)**	**2.54 (1.69; 3.82)**	0.77 (0.52; 1.13)
FTO AT (rs9939609)	Overall	3	T	TT	1.21 (0.85; 1.71)	1.19 (0.82; 1.74)	1.12 (0.83; 1.50)
IGF1 CT (rs35767)	Overall	2	C	CC	1.52 (0.88; 2.62)	N/A	1.34 (0.88; 2.04)
IL6-174 GC (rs1800795)	Overall	4	G	GG	**0.67 (0.47; 0.94)**	0.75 (0.35; 1.59)	**0.51 (0.35; 0.74)**
GNB3 CT (rs5443)	Overall	2	C	CC	1.10 (0.73; 1.66)	1.16 (0.68; 1.95)	1.20 (0.87; 1.65)
NOS3 TC (rs2070744)	Overall	2	T	TT	***0.54 (0.35; 0.81)***	***0.43 (0.22; 0.84)***	***0.37 (0.22; 0.64)***

Abbreviation: OR, odds ratio; CI, confidence interval; HMGT, homogenous genotype; HTGT, heterogeneous genotype; N/A, not available.
[a] Calculated OR and 95%CI based on allele frequency (minor allele versus major allele).
[b] Calculated OR and 95%CI based on genotype frequency (homozygote genotype of minor allele versus wildtype).
[c] Calculated OR and 95%CI based on genotype frequency (heterozygote genotype of minor allele versus wildtype).

95% = 0.31; 0.61) compared to the preferential genotype for power athlete status (GG) among the male subgroup. With regard to SNP rs2070744 of the *NOS3* gene, athletes carrying the C allele were significantly 0.54 (95%CI = 0.35; 0.81) less likely to become power athlete compared to athletes carrying the T allele. Additionally, significance was observed for the CC genotype (OR = 0.431; 95%CI = 0.22; 0.84) and TC genotype (OR = 0.37; 95%CI = 0.22; 0.64) compared to the preferential genotype for power athlete status (TT).

In Table 4 the results of all genes with only one study per SNP are presented. These SNPs are *ADRB1* (rs1801253), *ADRB2* (rs1042713, rs1042714), *ADRB3* (rs4994), *CNTFR* (rs3745672), *IGF1* (rs35767), *IGF-IR* (rs1464430), *GDF-8* (rs1805086), *NOS3* (rs1799983), *NRF-2*(rs12594956, rs7181866, rs8031031) and *SOD2* (rs4880). At the SNP rs1799725 of the *MnSOD* gene, having the TT genotype resulted in a significantly 2.70 (95%CI = 1.08; 6.72) times and having the CT genotype in a significantly 2.35 (95%CI = 1.21; 4.55) times lower chance of becoming a power athlete compared to

Please cite this article in press as: Weyerstraß J, et al. Nine genetic polymorphisms associated with power athlete status – A Meta-Analysis. *J Sci Med Sport* (2017), http://dx.doi.org/10.1016/j.jsams.2017.06.012

Table 3
Subgroup-analyses of the association between the genetic polymorphisms of the investigated genes and power athlete status.

Gene	Subgroup analysis	No. of studies	Major allele	Wildtype	Allele based OR[a] (95%CI)	HMGT based OR[b] (95%CI)	HTGT based OR[c] (95%CI)
ACE AG (rs4363)	Jamaican	1	A	AA	1.088 (0.616; 1.920)	0.966 (0.485; 1.926)	1.416 (0.872; 2.300)
	US African American	1	A	AA	1.200 (0.687; 2.096)	1.289 (0.602; 2.761)	**2.179 (1.190; 3.991)**
ACE ID (rs1799752)	African	2	D	DD	1.000 (0.672; 1.488)	0.951 (0.431; 2.097)	1.189 (0.827; 1.709)
	Caucasian	3	D	DD	0.867 (0.580; 1.296)	0.624 (0.383; 1.018)	**0.638 (0.412; 0.988)**
	Males, females	5	D	DD	0.757 (0.565; 1.016)	0.685 (0.391; 1.200)	0.803 (0.546; 1.182)
	Males	1	D	DD	1.299 (0.734; 2.296)	1.034 (0.345; 3.101)	1.310 (0.444; 3.869)
	European	1	D	DD	**0.460 (0.247; 0.857)**	N/A	0.681 (0.277; 1.673)
	Jamaican	1	D	DD	1.177 (0.672; 2.062)	1.380 (0.725; 2.629)	1.364 (0.823; 2.260)
	US African American	1	D	DD	**0.800 (0.702; 0.912)**	0.615 (0.281; 1.344)	1.026 (0.609; 1.730)
ACTN3 CT (*rs1815739*)	African	2	C	CC	0.893 (0.521; 1.532)	0.839 (0.290; 2.422)	0.909 (0.631; 1.311)
	Caucasian	15	C	CC	**0.765 (0.660; 0.887)**	**0.531 (0.423; 0.666)**	**0.835 (0.706; 0.987)**
	Asian	1	C	CC	0.845 (0.485; 1.472)	**0.704 (0.522; 0.951)**	0.793 (0.611; 1.028)
	Males, females	13	C	CC	**0.827 (0.703; 0.974)**	**0.610 (0.477; 0.781)**	0.881 (0.734; 1.057)
	Males	7	C	CC	**0.755 (0.608; 0.938)**	**0.516 (0.381; 0.698)**	0.880 (0.698; 1.109)
	European	1	C	CC	1.085 (0.620; 1.900)	1.048 (0.468; 2.348)	1.280 (0.694; 2.360)
	Jamaican	1	C	CC	1.000 (0.450; 2.223)	1.349 (0.330; 5.513)	0.924 (0.551; 1.550)
	US African American	1	C	CC	0.812 (0.391; 1.688)	0.456 (0.092; 2.249)	0.895 (0.534; 1.501)
	Spanish	2	C	CC	0.933 (0.627; 1.387)	0.804 (0.475; 1.362)	1.010 (0.699; 1.461)
	Polish	2	C	CC	0.854 (0.564; 1.292)	0.585 (0.335; 1.022)	0.984 (0.735; 1.316)
	Russian	2	C	CC	0.751 (0.503; 1.120)	**0.473 (0.265; 0.844)**	1.175 (0.769; 1.795)
AGT CT (rs699)	Males, females	1	T	TT	**1.863 (1.062; 3.267)**	**2.888 (1.644; 5.072)**	0.918 (0.526; 1.602)
	Males	2	T	TT	1.468 (0.989; 2.180)	**2.198 (1.211; 3.990)**	0.653 (0.381; 1.117)
FTO AT (rs9939609)	Spanish	1	T	TT	1.846 (0.892; 3.822)	1.829 (0.446; 7.499)	2.286 (0.712; 7.338)
	Polish	1	T	TT	1.020 (0.584; 1.783)	1.027 (0.553; 1.906)	1.052 (0.649; 1.706)
	Russian	1	T	TT	1.111 (0.629; 1.962)	1.242 (0.748; 2.063)	1.071 (0.728; 1.576)
IL6-174 GC (rs1800795)	Males, females	1	G	GG	1.244 (0.588; 2.632)	N/A	0.876 (0.473; 1.622)
	Males	3	G	GG	**0.576 (0.406; 0.818)**	**0.526 (0.331; 0.834)**	**0.430 (0.306; 0.606)**

Abbreviation: OR, odds ratio; CI, confidence interval; HMGT, homogenous genotype; HTGT, heterogeneous genotype; N/A, not available.
[a] Calculated OR and 95%CI based on allele frequency (minor allele versus major allele).
[b] Calculated OR and 95%CI based on genotype frequency (homozygote genotype of minor allele versus wildtype).
[c] Calculated OR and 95%CI based on genotype frequency (heterozygote genotype of minor allele versus wildtype).

Table 4
Meta-analyses of the association between the genetic polymorphisms of the investigated genes and power athlete status with one study per SNP.

Gene	Subgroup analysis	No. of studies	Major allele	Wildtype	Allele based OR[a] (95%CI)	HMGT based OR[b] (95%CI)	HTGT based OR[c] (95%CI)
ADRB1 AG (rs1801253)	Overall	1	C	CC	1.16 (0.65; 2.07)	1.43 (0.48; 4.30)	1.09 (0.53; 2.22)
ADRB2 GA (rs1042713)	Overall	1	G	GG	0.66 (0.37; 1.15)	0.46 (0.18; 1.18)	0.81 (0.39; 1.71)
ADRB2 GC (rs1042714)	Overall	1	C	CC	0.96 (0.53; 1.73)	0.92 (0.33; 2.57)	0.97 (0.47; 2.00)
ADRB3 TA (rs4994)	Overall	1	T	TT	2.79 (0.85; 9.14)	N/A	2.41 (0.87; 6.67)
CNTFR CT (rs3745672)	Overall	1	C	CC	0.98 (0.54; 1.80)	1.30 (0.76; 2.22)	1.00 (0.73; 1.38)
IGF-IR AC (rs1464430)	Overall	1	C	CC	1.62 (0.90; 2.91)	N/A	1.30 (0.69; 2.46)
GDF-8 AT (rs1805086)	Overall	1	A	AA	0.48 (0.14; 1.65)	N/A	0.94 (0.27; 3.27)
MCT1 AT (rs1049434)	Overall	1	A	AA	0.82 (0.44; 1.53)	0.53 (0.19; 1.44)	1.02 (0.56; 1.85)
MnSOD CT (rs1799725)	Overall	1	C	CC	1.588 (0.897; 2.812)	**2.70 (1.08; 6.72)**	**2.35 (1.21; 4.55)**
NOS3 GT (rs1799983)	Overall	1	G	GG	0.53 (0.28; 1.00)	***0.34 (0.13; 0.90)***	***0.48 (0.29; 0.79)***
NRF-2 AC (rs12594956)	Overall	1	A	AA	1.21 (0.70; 2.11)	1.75 (0.50; 6.20)	1.74 (0.60; 5.09)
NRF-2 AG (rs7181866)	Overall	1	A	AA	0.51 (0.11; 2.33)	N/A	0.56 (0.12; 2.66)
NRF-2 CT (rs8031031)	Overall	1	C	CC	N/A	N/A	0.95 (0.04; 23.77)
SOD2 CT (rs4880)	Overall	1	C	CC	0.83 (0.48; 1.45)	***0.68 (0.47; 0.98)***	0.97 (0.72; 1.30)

Abbreviation: OR, odds ratio; CI, confidence interval; HMGT, homogenous genotype; HTGT, heterogeneous genotype; N/A, not available.
[a] Calculated OR and 95%CI based on allele frequency (minor allele versus major allele).
[b] Calculated OR and 95%CI based on genotype frequency (homozygote genotype of minor allele versus wildtype).
[c] Calculated OR and 95%CI based on genotype frequency (heterozygote genotype of minor allele versus wildtype).

Please cite this article in press as: Weyerstraß J, et al. Nine genetic polymorphisms associated with power athlete status – A Meta-Analysis. *J Sci Med Sport* (2017), http://dx.doi.org/10.1016/j.jsams.2017.06.012

the preferential genotype for power athlete status (CC). The SNP rs1799983 of the *NOS3* gene yielded significance for the TT genotype (OR = 0.34; 95%CI = 0.13; 0.90) and GT genotype (OR = 0.48; 95%CI = 0.29; 0.79). At the SNP rs4880 of the *SOD2* gene, the TT genotype yielded significance with an OR of 0.68 (95%CI = 0.47; 0.98) meaning that athletes having this genotype were 0.68 times less likely to become a power athlete compared to athletes having the CC genotype. Overall no significant associations between the SNPs of the *ADRB1* (rs1801253), *ADRB2* (rs1042713, rs1042714), *ADRB3* (rs4994), *CNTFR* (rs3745672), *FTO* (rs9939609), *IGF1* (rs35767), *IGF-IR* (rs1464430), *GDF-8* (rs1805086), *GNB3* (rs5443), *MCT1* (rs1049434) and *NOS3* (rs1799983, rs2070744, rs12594956) gene and power athlete status were observed.

4. Discussion

The purpose of this meta-analysis was to investigate genetic polymorphisms associated with power athlete status and possible interference by race and sex. In total 35 articles were found eligible for this meta-analysis published between 2008 and 2016. Significant associations were found for 9 polymorphisms in the *ACE* (rs4363, rs1799752), *ACTN3* (rs1815739), *AGT* (rs699), *IL6-174* (rs1800795), *MnSOD* (rs1799725), *NOS3* (rs1799983, rs2070744) and *SOD2* (rs4880) genes, with some differential effects between subgroups of sex and/or race.

Results of this meta-analysis show that US African American carriers of the *ACE* AG genotype (rs4363) were more than two times more likely to become a power athlete compared to carriers of the *ACE* preferential genotype for power athlete status (AA) in this population. This association turned out not to be significant in the Jamaican population, even though the included power athletes were highly comparable to the power athletes used in the US African American population regarding the competitive level as both populations consisted of "extremely elite athletes".[21] One possible explanation is that both, the Jamaican power athletes and the Jamaican controls, had a high prevalence of the *ACE* preferential genotype for power athlete status (AA) with a proportion of 34% and 40% respectively, meaning that a larger sample size would be required to achieve statistical significance.

For the *ACE* ID polymorphism (rs1799752), the subgroup analyses show that carriage of the insertion allele in a European population (OR = 0.46; 95%CI = 0.25; 0.86) and US African Americans (OR = 0.80; 95%CI = 0.70; 0.91) as well as having the *ACE* ID genotype in Caucasians (OR = 0.64; 95%CI = 0.41; 0.99) is less beneficial for becoming a power athlete. As the *ACE* insertion allele is overrepresented in endurance athletes[22] the present findings indicate that the absence of the insertion might be an advantage for becoming a power athlete. A significant association of the *ACE* D allele with elite power athlete status was also observed by several other studies,[23] suggesting that the *ACE* D allele can be considered as a power allele. Contrary results were obtained by Shahmoradi et al.,[24] who found a higher proportion of the D allele in long distance cyclists of elite level, which would mean that the D allele is beneficial for endurance sports and not for power-related sports. This finding is also supported by Amir et al.,[25] who observed a higher frequency of the *ACE* D allele in Israeli elite endurance athletes compared to Israeli elite sprinters (77% vs. 57%). With regard to the *ACE* ID genotype in Caucasians, higher frequencies of this genotype were found in Polish and Caucasian long distance swimmers by Grenda et al.[26] confirming the result of this study, that the *ACE* ID genotype might be less beneficial for becoming a power athlete as Caucasian. It should be note, however, that the contradictory findings might also be caused be the different kind of sport disciplines examined in the different studies. It is questionable whether the profile for power athletes in short distance swimming, sprinting and short distance cycling are similar.

The results for the *ACTN3* CT polymorphism (rs1815739) show that carriers of the T allele compared to carriers of the C allele were significantly 0.80 (95%CI = 0.70; 0.91) times less likely to become a power athlete. Additionally, athletes having the TT genotype compared to the preferential genotype for power athlete status (CC) were 0.58 (95%CI = 0.48; 0.70) times less likely to become a power athlete indicating that the *ACTN3* T allele as well as the TT genotype is negatively associated with power athlete status. Additionally, in Caucasians, athletes having the CT genotype were significantly less likely (OR = 0.84; 95%CI = 0.42; 0.67) to become a power athlete. Present findings were supported by the literature, which stated that *ACTN3*C allele and CC genotype are associated with power athlete status.[17,27] Even though the CT genotype was more present in strength athletes, the same study found an underrepresentation of the T allele in the used population indicating that C allele carriage might be beneficial for both; power and strength related sports.

Results of the *AGT* CT polymorphism (rs699) show that C allele carriage (OR = 1.59; 95%CI = 1.15; 2.20) and having the CC genotype (OR = 2.54; 95%CI = 1.69; 3.82) was positively associated with power athlete status in Caucasian elite and top national level power athletes.[28–30] As the *ACE* D allele uses the same pathway and is associated with power athlete status, literature suggested that the *AGT* C allele might be beneficial a well for becoming a power athlete.[31] Although this study found a positive association of the *AGT* C allele and power athlete status, up to date a definitive conclusion about a possible advantage of C allele carriage for power related sports cannot be made.

The *IL6-174* GC polymorphism (rs1800795) obtained negative significant associations with power athlete status for *IL6-174*C allele versus G allele carriage (OR = 0.67; 95%CI = 0.47; 0.94) and having the CC (OR = 0.53; 95% = 0.33; 0.83) as well as having the GC genotype (OR = 0.43; 95% = 0.31; 0.61) compared to the preferential genotype for power athlete status (GG) in 3 male Caucasian populations.[32,33] These findings indicate that the G allele as well as the GG genotype might be beneficial for becoming a power athlete. However, no significant association between the G allele and power athlete status was found.[34]

The *MnSOD* CT polymorphism (rs1799725) yielded a positive association with power athlete status for having the TT genotype (OR = 2.70; 95%CI = 1.08; 6.72) and having the CT genotype (OR = 2.35; 95%CI = 1.21; 4.55) compared to having the preferential genotype for power athlete status (CC) in Caucasians,[35] suggesting an advantage of having the TT and CT genotype for becoming a power athlete in this population. As well as for the *AGT* C allele, a definitive conclusion cannot be made due to limited literature which can support these findings.

In this study, 2 genetic polymorphisms of the *NOS3* gene were included, the G894T (rs1799983) and T786C polymorphism (rs2070744). Power athletes in these studies were Caucasian sprinters, jumpers and throwers.[29,36,37] With regard to SNP rs1799983, having the G (OR = 0.34; 95%CI = 0.13; 0.90) and GT genotype (OR = 0.48; 95%CI = 0.29; 0.79) was negatively associated with power athlete status. For the SNP rs2070744, the C allele was less favorable for becoming a power athlete (OR = 0.54; 95%CI = 0.35; 0.81) compared to the T allele indicating that carriers of the T allele are more likely to become a power athlete than non-carriers of the T allele. These findings are supported by the literature, which found a higher frequency of the T allele in power athletes compared to sedentary controls.[38]

The last tested genetic polymorphism in this study was the *SOD2* CT polymorphism (rs4880). Power athletes in this study were Russian and Caucasian.

At the SNP rs4880, the TT genotype yielded a negative significant association (OR = 0.68; 95%CI = 0.47; 0.98) with power athlete

Please cite this article in press as: Weyerstraß J, et al. Nine genetic polymorphisms associated with power athlete status – A Meta-Analysis. *J Sci Med Sport* (2017), http://dx.doi.org/10.1016/j.jsams.2017.06.012

status compared to the preferential genotype for power athlete status (CC). Therefore, athletes having the TT genotype were 0.68 less likely to become a power athlete compared to athletes having the preferential genotype for power athlete status (CC). The findings for the SNP rs4880 of the *SOD2* gene cannot be supported yet but also other literature stated an association of *SOD2* CT with power athlete status.[39] Nevertheless, more literature is needed to draw a comprehensive conclusion about this association.

No significant associations with power athlete status were observed for the *ADRB1* (rs1801253), *ADRB2* (rs1042713, rs1042714), *ADRB3* (rs4994), *CNTFR* (rs3745672), *FTO* (rs9939609), *IGF1* (rs35767), *IGF-IR* (rs1464430), *GDF-8GDF-8* (rs1805086), *GNB3* (rs5443), *MCT1* (rs1049434) and *NRF-2* (rs12594956, rs7181866, rs8031031) polymorphisms.

Although a large number of the investigated genetic polymorphisms in this meta-analysis have only been investigated in a single study (13 out of the 23 SNPs) and showed no significantly associated with the status of being a power athlete it cannot be ruled that some of these genetic polymorphisms can still be favorable for becoming a power athlete, which represents a limitation of this study. More studies for these particular genes need to be done to make a final conclusion about the association of the provided alleles and genotypes with power athlete status.

Another limitation besides low sample size and number of studies was the problem with insufficient data for OR calculation. Some of the used studies included genotype frequencies of 0, so an OR could not be calculated, which leads to non-significant results.

5. Conclusion

In conclusion, ten genetic polymorphisms have been identified in the meta-analyses to have a significant association with the status of being a power athlete. Nevertheless, more research on the investigated genes needs to be done to draw comprehensive conclusions about a gene and its association with power athlete status. Additionally, it is recommended for future research to include sufficient participants in the studies to achieve a high power and therefore increasing the chance to detect significant differences of allele and genotype frequencies between the power athletes and controls for each genetic polymorphism.

Acknowledgements

This meta-analysis was supported by the Department of Complex Genetics, as well as by the School of Nutrition and Translational Research in Metabolism (NUTRIM) of the Maastricht University Medical Centre.

References

1. Gettman LR, Pollock ML. What makes a superstar? A physiological profile. *Phys Sportsmed* 1977; 5(5):64–68.
2. Elliott MC, Wagner PP, Chiu L. Power athletes and distance training: physiological and biomechanical rationale for change. *Sports Med (Auckland, NZ)* 2007; 37(1):47–57.
3. Tancred B. Key methods of sports conditioning. *Athletics Coach* 1995; 29(2):19.
4. Sapega AA, Drillings G. The definition and assessment of muscular power. *J Orthop Sports Phys Ther* 1983; 5(1):7–9.
5. Fitts RH, McDonald KS, Schluter JM. The determinants of skeletal muscle force and power: their adaptability with changes in activity pattern. *J Biomech* 1991; 24(Suppl. 1):111–122.
6. Costill DL, Daniels J, Evans W et al. Skeletal muscle enzymes and fiber composition in male and female track athletes. *J Appl Physiol* 1976; 40(2):149–154.
7. Fry AC, Schilling BK, Staron RS et al. Muscle fiber characteristics and performance correlates of male plympic-style weightlifters. *J Strength Cond Res* 2003; 17(4):746–754.
8. De Moor MH, Spector TD, Cherkas LF et al. Genome-wide linkage scan for athlete status in 700 British female DZ twin pairs. *Twin Res Hum Genet* 2007; 10(6):812–820.
9. Williams AG, Folland JP. Similarity of polygenic profiles limits the potential for elite human physical performance. *J Physiol* 2008; 586(1):113–121.
10. Kiss MAPDM, Böhme MTS, Mansoldo AC et al. Performance and sports talent. *Rev Paul Educ Fís* 2004; 19:89–100.
11. Ostrander EA, Huson HJ, Ostrander GK. Genetics of athletic performance. *Annu Rev Genom Hum Genet* 2009; 10:407–429.
12. Ahmetov II, Fedotovskaya ON. Sports genomics: current state of knowledge and future directions. *Cell Mol Exerc Physiol* 2012; 1(1):1–25.
13. Guth LM, Roth SM. Genetic influence on athletic performance. *Curr Opin Pediatr* 2013; 25(6):653–658.
14. Cieszczyk P, Eider J, Ostanek M et al. Association of the ACTN3 R577X polymorphism in polish power-orientated athletes. *J Hum Kinet* 2011; 28:55–61.
15. MacArthur DG, North KN. A gene for speed? The evolution and function of alpha-actinin-3. *Bioessays* 2004; 26(7):786–795.
16. Seto JT, Quinlan KG, Lek M et al. ACTN3 genotype influences muscle performance through the regulation of calcineurin signaling. *J Clin Invest* 2013; 123(10):4255–4263.
17. Yang N, MacArthur DG, Gulbin JP et al. ACTN3 genotype is associated with human elite athletic performance. *Am J Hum Genet* 2003; 73(3):627–631.
18. Ma F, Yang Y, Li X et al. The association of sport performance with ACE and ACTN3 genetic polymorphisms: a systematic review and meta-analysis. *PLoS One* 2013; 8(1):e54685.
19. Macarthur DG, North KN. Genes and human elite athletic performance. *J Hum Genet* 2005; 116(5):331–339.
20. North KN, Yang N, Wattanasirichaigoon D et al. A common nonsense mutation results in alpha-actinin-3 deficiency in the general population. *Nat Tenet* 1999; 21(4):353–354.
21. Scott RA, Irving R, Irwin L et al. ACTN3 and ACE genotypes in elite Jamaican and US sprinters. *Med Sci Sports Exerc* 2010; 42(1):107–112.
22. Gayagay G, Yu B, Hambly B et al. Elite endurance athletes and the ACE I allele—the role of genes in athletic performance. *J Hum Genet* 1998; 103(1):48–50.
23. Gineviciene V, Jakaitiene A, Aksenov M et al. Association analysis of ACE, ACTN3 and PPARGC1A gene polymorphisms in two cohorts of European strength and power athletes. *Biol Sport* 2016; 33(3):199–206. http://dx.doi.org/10.5604/20831862.1201051.
24. Shahmoradi S, Ahmadalipour A, Salehi M. Evaluation of ACE gene I/D polymorphism in Iranian elite athletes. *Adv Biomed Res* 2014; 3:207.
25. Amir O, Amir R, Yamin C et al. The ACE deletion allele is associated with Israeli elite endurance athletes. *Exp Physiol* 2007; 92(5):881–886.
26. Grenda A, Leonska-Duniec A, Kaczmarczyk M et al. Interaction between ACE I/D and ACTN3 R557X polymorphisms in polish competitive swimmers. *J Hum Kinet* 2014; 42:127–136.
27. Niemi AK, Majamaa K. Mitochondrial DNA and ACTN3 genotypes in Finnish elite endurance and sprint athletes. *Eur J Hum Genet* 2005; 13(8):965–969.
28. Gomez-Gallego F, Santiago C, Gonzalez-Freire M et al. The C allele of the AGT Met235Thr polymorphism is associated with power sports performance. *Appl Physiol Nutr Metab* 2009; 34(6):1108–1111.
29. Ruiz JR, Arteta D, Buxens A et al. Can we identify a power-oriented polygenic profile? *J Appl Physiol (Bethesda, Md: 1985)* 2010; 108(3):561–566.
30. Zarebska A, Sawczyn S, Kaczmarczyk M et al. Association of rs699 (M235T) polymorphism in the AGT gene with power but not endurance athlete status. *J Strength Cond Res* 2013; 27(10):2898–2903.
31. Eynon N, Hanson ED, Lucia A et al. Genes for elite power and sprint performance: ACTN3 leads the way. *Am J Sports Med (Auckland, NZ)* 2013; 43(9):803–817.
32. Eider J, Cieszczyk P, Leonska-Duniec A et al. Association of the 174 G/C polymorphism of the IL6 gene in Polish power-orientated athletes. *J Sports Med Phys Fitness* 2013; 53(1):88–92.
33. Ruiz JR, Buxens A, Artieda M et al. The −174 G/C polymorphism of the IL6 gene is associated with elite power performance. *J Sci Med Sport* 2010; 13(5):549–553.
34. Eynon N, Ruiz JR, Meckel Y et al. Is the −174 C/G polymorphism of the IL6 gene associated with elite power performance? A replication study with two different Caucasian cohorts. *Exp Physiol* 2011; 96(2):156–162.
35. Ben-Zaken S, Eliakim A, Nemet D et al. Increased prevalence of MnSOD genetic polymorphism in endurance and power athletes. *Free Radic Res* 2013; 47(12):1002–1008.
36. Eider J, Ficek K, Kaczmarczyk M et al. Endothelial nitric oxide synthase g894t (rs1799983) gene polymorphism in polish athletes. *Open Life Sci* 2014; 9(3):260–267.
37. Gomez-Gallego F, Ruiz JR, Buxens A et al. The −786 T/C polymorphism of the NOS3 gene is associated with elite performance in power sports. *Eur J Appl Physiol* 2009; 107(5):565–569.
38. Sessa F, Chetta M, Petito A et al. Gene polymorphisms and sport attitude in Italian athletes. *Genet Test Mol Biomarkers* 2011; 15(4):285–290.
39. Ahmetov II, Naumov VA, Donnikov AE et al. SOD2 gene polymorphism and muscle damage markers in elite athletes. *Free Radic Res* 2014; 48(8):948–955.
41. Costa AM, Silva AJ, Garrido ND et al. Association between ACE D allele and elite short distance swimming. *Eur J Appl Physiol* 2009; 106(6):785–790.
42. Eider J, Cieszczyk P, Ficek K et al. The association between D allele of the ACE gene and power performance in Polish elite athletes. *Sci Sports* 2013; 28(6):325–330.
43. Papadimitriou I, Papadopoulos C, Kouvatsi A et al. The ACE I/D polymorphism in elite Greek track and field athletes. *J Sports Med Phys Fitness* 2009; 49(4):459.
44. Cieszczyk P, Sawczuk M, Maciejewska-Karlowska A et al. ACTN3 R577X polymorphism in top-level Polish rowers. *J Exerc Sci* 2012; 10(1):12–15.

Please cite this article in press as: Weyerstraß J, et al. Nine genetic polymorphisms associated with power athlete status – A Meta-Analysis. *J Sci Med Sport* (2017), http://dx.doi.org/10.1016/j.jsams.2017.06.012

45. Eynon N, Banting LK, Ruiz JR et al. ACTN3 R577X polymorphism and team-sport performance: a study involving three European cohorts. *J Sci Med Sport* 2014; 17(1):102–106.
46. Eynon N, Ruiz JR, Femia P et al. The ACTN3 R577X polymorphism across three groups of elite male European athletes. *PLoS One* 2012; 7(8):e43132.
47. Papadimitriou I, Papadopoulos C, Kouvatsi A et al. The ACTN3 gene in elite Greek track and field athletes. *Int J Sports Med* 2008; 29(04):352–355.
48. Bell W, Colley J, Evans W et al. ACTN3 genotypes of Rugby Union players: distribution, power output and body composition. *Ann Hum Biol* 2012; 39(1):19–27.
49. Druzhevskaya AM, Ahmetov II, Astratenkova IV et al. Association of the ACTN3 R577X polymorphism with power athlete status in Russians. *Eur J Appl Physiol* 2008; 103(6):631–634.
50. Garatachea N, Verde Z, Santos-Lozano A et al. ACTN3 R577X polymorphism and explosive leg-muscle power in elite basketball players. *Int J Sports Physiol Perform* 2014; 9(2):226–232.
51. Hong SS, Jin HJ. Assessment of association of ACTN3 genetic polymorphism with Korean elite athletic performance. *Genes Genom* 2013; 35(5):617–621.
52. Kikuchi N, Miyamoto-Mikami E, Murakami H et al. ACTN3 R577X genotype and athletic performance in a large cohort of Japanese athletes. *Eur J Sport Sci* 2016; 16(6):694–701.
53. Ruiz JR, Santiago C, Yvert T et al. ACTN3 genotype in Spanish elite swimmers: no "heterozygous advantage". *Scand J Med Sci Sports* 2013; 23(3):e162–e167.
54. Santiago C, Ruiz JR, Buxens A et al. Trp64Arg polymorphism in ADRB3 gene is associated with elite endurance performance. *Br J Sports Med* 2011; 45(2):147–149.
55. Miyamoto-Mikami E, Fujita Y, Murakami H et al. CNTFR genotype and sprint/power performance: case-control association and functional studies. *Int J Sports Med* 2016; 37(05):411–417.
56. Ben-Zaken S, Meckel Y, Dror N. IGF-I and IGF-I receptor polymorphisms among elite swimmers. *Pediatr Exerc Sci* 2014; 26(4):470–476.
57. Ben-Zaken S, Meckel Y, Nemet D et al. Can IGF-I polymorphism affect power and endurance athletic performance? *Growth Horm IGF Res* 2013; 23(5):175–178.
58. Eynon N, Nasibulina ES, Banting LK et al. The FTO A/T polymorphism and elite athletic performance: a study involving three groups of European athletes. *PLoS One* 2013; 8(4):e60570.
59. Sawczuk M, Maciejewska-Karłowska A, Cięszczyk P et al. Is GNB3 C825T polymorphism associated with elite status of polish athletes. *Biol Sport* 2014; 31:21–25.
60. Ruiz JR, Eynon N, Meckel Y et al. GNB3 C825T polymorphism and elite athletic status: a replication study with two ethnic groups. *Int J Sports Med* 2011; 32(02):151–153.
61. Ben-Zaken S, Eliakim A, Nemet D et al. Differences in MCT1 A1470T polymorphism prevalence between runners and swimmers. *Scand J Med Sci Sports* 2015; 25(3):365–371.
62. Eynon N, Ruiz JR, Bishop DJ et al. The rs12594956 polymorphism in the NRF-2 gene is associated with top-level Spanish athlete's performance status. *J Sci Med Sport* 2013; 16(2):135–139.

Please cite this article in press as: Weyerstraß J, et al. Nine genetic polymorphisms associated with power athlete status – A Meta-Analysis. *J Sci Med Sport* (2017), http://dx.doi.org/10.1016/j.jsams.2017.06.012