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REVIEW ARTICLE

Conventional and Genetic Talent Identification in Sports: Will Recent Developments Trace Talent?

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Abstract The purpose of talent identification (TI) is the earliest possible selection of auspicious athletes with the goal of systematically maximizing their potential. The literature proposes excellent reviews on various facets of talent research on different scientific issues such as sports sciences or genetics. However, the approaches of conventional and genetic testing have only been discussed separately by and for the respective groups of interest. In this article, we combine the discoveries of these disciplines into a single review to provide a comprehensive overview and elucidate the prevailing limitations. Fundamental problems in TI reside in the difficulties of defining the construct 'talent' or groups of different performance levels that represent the target variable of testing. Conventional and genetic testing reveal a number of methodological and technical limitations, and parallels are summarised in terms of the test designs, the point in time of testing, psychological skills or traits and unknown interactions between different variables. In conclusion, many deficiencies in the current talent research have gained attention. Alternative solutions include the talent development approach, while genetic testing is re-emphasised as a tool for risk stratification in sport participation. Future research needs to clearly define the group of interest and comprehensively implement all methodological improvement suggestions.

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1 Introduction

Elite sport does not only require individual top performance. High-performance athletes represent their country and association and compete for fame, public recognition, sponsorship and prize money. The pursuit of greatness and the increasing commercialisation of sports cause associations and clubs to employ their resources for performance promotion [1]. The current example of the soccer player Gareth Bale, for whom Real Madrid paid a fee of €100 million, reflects the prevailing economic pressure. Due to economic principles, the available resources are focused on systematic programmes to provide at least some athletes the opportunity to utilise their maximum potential [2]. The athletes who are eligible for support must be selected from the crowd, and this selection is achieved through talent identification (TI) programmes based on certain criteria. These criteria are designed to reflect key skills that project the potential of a young person on his athletic performance in adulthood.

Although the criteria have been subjected to multidisciplinary research and detailed discussion, the optimal test design for a reliable prediction of talent has not yet been found [3–5]. Possible reasons might be inherent in the fact that the variable being measured is not very well comprehended. Finding a comprehensive definition of a 'sports talent' in the literature is challenging. An objective approach may be translated from a German version of Hohmann and Seidel [6]:

> A talent in sports is a person, whose athletic performance capabilities are, by taking into account the training experience, above-average compared to a reference group of similar biological development status and similar life habits, and for whom it is

mathematically-simulatively predicted or retrospectively stated, that he or she will reach or has achieved athletic top performance, by considering endogenous performance dispositions and feasible exogenous performance conditions (p. 185).

However, several authors dealing with any aspect of a 'talented person' note an inherent problem: the talent concept has been widely but indiscriminantly observed and utilised [7], while, typically, geno-centric or environmentalist positions were adopted for its explanation (the so-called nature–nurture debate) [8–11]. Some models were based more on the hypothesis that talent is genetically transmitted or that success in a given domain is innately contributed ('innate' talent that is sometimes synonymously used with giftedness) [12–14]. An example may be given by citing Howe et al. [15]: "early ability is not evidence of talent unless it emerges in the absence of special opportunities to learn" (p. 403). Gagné [16–18], therefore, differentiated between giftedness and talent. Giftedness was defined as exceptional competence in one or more domains of ability. In the presence of relevant environmental and personality factors, talent was described as exceptional performance in one or more fields of human activity developing from these domains of abilities. Other authors considered talent as being inherited (early gifted), but success or high-performance levels in the domain as being only, to a small degree, amenable to this attribute. Success or high performance are rather traced to environmental factors such as training and assessment approaches [19–21], and therefore the developmental process of a person and his or her capabilities is emphasised as being more important than the degree of inherited gifts (talent development). Baker et al. [22] supported this position by stating that the refinement of certain inherited, general traits such as intelligence into domain-specific abilities such as pattern recognition and strategic actions occurred only after years of intense training.

This unsatisfactory starting position shall now be left open because the present article will not clarify the outstanding questions of the nature–nurture debate. In view of and despite the above, the following sections consider talent (re)search in sport in terms of intersections, strengths and deficiencies of conventional and genetic testing (GT) and how they may contribute to TI. There have been excellent reviews on various facets of talent research in sports practical, sports medical, psychological, ethical or scientific issues (for example see Williams and Reilly [23–27], Abott et al. [23–27], Pearson et al. [23–27], Anshel and Lidor [23–27], and Roth [23–27]). Both approaches are usually discussed separately by and for different groups of interest. In this article, we unify discoveries of these disciplines into a single review to provide a comprehensive and orienting overview on the current conventional measuring methods for TI and the emerging GT.

2 Conventional Talent Identification (TI)

Two basic approaches have been followed for the promotion of athletes: TI (which is usually followed by selection) and talent development. TI programmes are designed to recognize "a natural endowment or ability of a superior quality" (according to the current attempts to define 'talent'; p. 278; [25]) or "to identify young athletes who possess extraordinary potential for success in senior elite sport, and to select and recruit them into talent promotion programmes" (p. 1,367; [1]). The challenge of these programmes is to develop valid and reliable sport-specific test designs for the determination of a young athlete's current capabilities in a particular sport, to accelerate his or her development and to provide a predictive value for future performance or success [25, 28]. Talent development programmes focus less on current abilities but more on providing athletes with appropriate practice conditions to promote their future potential in a given sport [26]. Because the conventional talent promotion paradigm was mainly built on TI, this approach will be the prevailing subject of Sect. 2. Talent development will be taken into account less extensively here but emphasised again in the Discussion.

2.1 Study Designs for Conventional Talent (Re)Search

The TI process comprises the measurement and comparison of characteristic values that determine the sport-specific performance. The test items are derived from statistical path analyses exhibiting single variables that largely explain the complex performance. Sprint performance for example is primarily determined by body structure, basic running speed, and technical or coordination skills [29]. Based on such analyses, TI tests assess anthropometric variables such as stature, weight, limb circumferences, body composition or bone density, and physiologically relevant measures such as the maximum oxygen uptake, aerobic or anaerobic endurance, strength, flexibility, and sport-specific skills such as running and jumping performance or ball control [30–37]. To filter out the proper discriminates, researchers often compare different age groups or performance classes in a cross-sectional design: in top-down approaches, top-class athletes are compared with athletes of lower performance levels by assessing certain attributes. The attributes that reveal the most significant differences between the performance levels are determined to be discriminate or predictor variables.

In bottom-up approaches, the classification into elite or not elite follows the testing procedure by taking into account the most discriminating variables. Regression analysis from tests in male junior elite basketball players, for example, revealed vertical jumps, arm span and basketball throw as significant predictor variables [36]. However, 60 % of the total variance of basketball performance could not be explained and was speculated to be a combination of other perceptual or cognitive, psychological or sports-specific factors such as decision making or game sense. This example mirrors the low explanatory power of many other studies that will be discussed in detail below. Furthermore, the dependencies and interactions among the entirety of test items and other factors remain evidently unknown [3, 38, 39].

Criticism had been expressed concerning the one-dimensionality in the practice of TI [4, 38]. To obtain comprehensive and multidisciplinary testing [40–42], the test batteries were extended by tactical skills and items from other basic sciences such as psychology or sociology [41, 43, 44]. For example, soccer talents were reported to exhibit higher cognitive abilities in terms of understanding of the game, decision-making ability and anticipation [30, 32, 45, 46]. Further sport psychological evaluations found Olympic athletes to be especially confident, mentally tough and resilient, sport-intelligent, optimistic, adaptive perfectionist, competitive, hard working, coachable, able to cope with and control anxiety, focus and block out distractions, set and achieve goals, and to have a very hopeful disposition [47]. Important sociological factors influencing talent development have been found with respect to the environment, institutions, the coach and fellow participants [26, 41, 47–49] because they are likely to affect the athletes' decision making, motivation, habits, training and skill development [41, 50]. Investigation of social influences in sport has recently provided evidence that parents, coaches and athletes impact on the relative age effect (see Sect. 2.2) through social perception, self-fulfilling biases and the coaching process [51]. However, recent TI models are not able to provide a holistic profile of the psychological characteristics of champions [47] and lack the understanding of the social impact of peers, culture, media and other competing activities. The reasons for these deficiencies are inherent in the validity of the available tests. Anshel and Lidor [26], for instance, summarised that psychological tests such as the 'Profile of Mood States' test (POMS) or the Minnesota Multiphasic Personality Inventory (MMPI) yielded no single characteristic or set of psychological measures to be sufficiently predictive of future athletic performance. Reilly et al. [30] suggested that TI programmes contain a coaching bias because the degree of expertise and impact of the coaches was rarely controlled.

2.2 Basic Issues That Reduce the Success of TI

The cross-sectional designs of most talent studies hide other problems in terms of attribute assessment, classification and transferability into TI programmes. The selection of sensitive, valid and reliable tests, that represent either the attributes of top athletes or the performance requirements of a certain sport, constitutes the first difficulty [25, 30, 34]. Furthermore, the classification into 'talented', 'elite' or 'successful' athletes versus 'less- or untalented', 'non- or sub-elite' or 'unsuccessful' [43, 52, 53] differs between the studies and depends most evidently on the availability of athlete groups for the studies. While Douda et al. [37] determined international competitors as 'elite athletes' and national competitors as 'non-elite' athletes, Matthys et al. [34] termed the best handball players in a national competition season as 'elite' and all other players as 'non-elite'. Inconsistency in determining an 'elite' athlete might also derive from the statistical procedures discriminating skill level as a function of an athlete's current achievement [26]. Many studies revealed only weak differences between high and lower performance levels that were insufficient for discrimination. Therefore, final conclusions remained superficial and insignificant [30, 32–34]. From a scientific perspective and for the purpose of TI, an appropriate definition of these performance classes remains necessary. However, we seriously need to question whether any clear line can ever be drawn between talented, elite, successful and untalented, non-elite, unsuccessful athletes. Considering the great discussion about the construct of 'talent' and the inability to measure it, a 'twilight zone' will always persist.

The problem of transferability in many disciplines arises from the early point in time of TI and selection. Although it has not yet been clarified whether early specialisation, diversification or engagement rather lead to top performance in adulthood [2, 54–59], there is research suggesting that athletes should pass through 10 years of intense practice until they reach peak performance [60]. Depending on the type of sport, the point in time of TI is therefore set at the ages of 6–15 years [1, 35–37, 44]. Because the variables or tests used to select the best athletes are usually derived from comparisons of adult top-class athletes, their transferability to children or adolescents is questionable. Most biomedical and motor tests only reach high reliability and validity in adults, while elementary and complex sport-related capacities in children remain difficult to judge [38, 41, 61]. Analyses of the stability of characteristics and capacities during the phase of psychophysical development provide different statements to which extent anthropometric measures and motor skills in childhood and adolescence can be projected to the future [3, 38, 62]. Physiological characteristics such as aerobic and anaerobic performance or grip strength tend to develop in late adolescence and thus may not be significant predictors in younger athletes [32].

Special attention must be awarded to maturation [1, 4]. Not only the athlete's chronological age but also biological maturation status play an important role in the development of sports performance [25, 33, 34, 62, 63]. The so-called relative age effect has been shown to be evident in various disciplines, with early-maturing athletes being preferentially selected in sports such as soccer and late-maturing athletes in gymnastics [35, 63]. The uneven birth date distribution in European high-class soccer players, for instance, was interpreted to strengthen the suggestion that talent selection is significantly influenced by a child's physique rather than its skills [63, 64]. Thereby, physical parameters such as height, muscular development or body fat deposition are known to be unreliable predictors because of large variations in growth potential during and following puberty, erroneous prediction methods and large standard deviations, or the complex interactions between genetics, hormone activity, nutrition and habits [25]. In adolescent handball players, the maturation status was also shown to affect many anthropometric and physical performance measures [34]. Furthermore, physiological characteristics such as anaerobic capacity or strength and sport-specific skills appear to be strongly linked to maturation, resulting from hormonal mediation and increased physical and cognitive abilities [25]. Longitudinal and retrospective studies revealed that late-maturing soccer and handball players were able to catch up with their earlier-maturing competitors, given the fact they were promoted in the meantime [33, 40]. Vice versa, Svetlana Khorkina is often mentioned as a successful example in the aesthetic-compositional disciplines (such as gymnastics, dance, or figure skating), although her early maturation and tall body size were expected to impede high-class performance in gymnastics. Thus, studies limited to childhood and adolescence achieve only reduced explaining power, while extrapolation may increase the risk of false positives [2, 38].

Furthermore, the test results depend on the specific point in time of testing with respect to the athlete's optimal training level, daily physical state and health [41, 65–68]. If an athlete is not able to show his or her best performance in the test situation, the results do not reflect his or her 'real' abilities. In a paper on 'player profiles' for the German Football Federation (DFB), Höner and Roth [67] described that the talent tests were, at least in individual cases, not representative of the current performance level and therefore covered only single aspects of what makes a good player.

In the context of sport-practical tests, we also need to consider aspects of trainability and inherited dispositions. Some test parameters, such as muscle and fat mass, are easily influenced by training and nutritional factors [69, 70]. Others, such as the stature, maximum oxygen uptake or psychological characteristics seem largely genetically predisposed, and are thus only little or at least less modifiable by training [23, 71]. Based on the unsolved problems in defining a talent, it is not surprising that we need to question whether the tests for TI should measure inherited traits, the best training status or the highest response rate to training interventions. It seems like sports scientists are neither asking nor answering this question. For example, Matthys et al. [34] stated "Elite players are expected to increase their physical performance level more rapidly during the 3 years [of a longitudinal study] (…) compared with their non-elite counterparts because of their higher training load." (p. 326). Although the elite players started from a higher physical performance level and might have shown a steeper increase in performance over the 3 years of the study, this statement implies that the difference between the performance level of elite and non-elite athletes might have rather been the result of different training loads (13 vs. 4.5 h per week) instead of being more talented. Reilly et al. [30] also concluded that the measures in their study were "to a certain degree amenable to training or practice effects" (p. 702).

As a way of addressing this unsatisfactory situation, an alternative approach of talent development instead of the conventional 'snap-shot' testing has been proposed. The talent development approach comprises a longitudinal system of talent support and guidance, including regular assessment of an athlete's actual proficiency with subsequent adaptation of appropriate training contents and environments [5, 21, 24, 41]. The advantages of this approach lie in the long-term monitoring of the athlete's physical, psychological and skill development [41] without hasty discrimination or (de)selection, solving shortcomings such as the dependency of talent testing from the point in time. However, disadvantages have been suggested concerning the complexity and cost effectiveness of this system, and the fact that the success of those programmes can only be evaluated retrospectively [41]. Similar to TI, research in the field of talent development faces multiple problems. For instance, the current state of research does not indicate whether early specialisation, diversification or engagement may form an athlete's best developmental pathway to top performance [57, 59].

In summary, we still have to face a multitude of difficulties in the diagnosis of sport-scientific, medical, psychological and social criteria of talent, despite decades of research (Table 1) [4, 23, 70]. The goal of several recent studies persists in reducing the test batteries again on a few items that best explain the difference between elite and non-elite athletes [32–35, 37, 53, 73]. The combination of finding the most sensitive test items, ensuring

Table 1 Deficiencies and limitations of conventional talent identification tests or studies concerning various methodological and ethical aspects

Aspects of conventional testing	Deficiencies and limitations	References
Basic constructs	'Talent' or 'elite athlete' either not defined or defined inexactly or arbitrarily Nature–nurture-debate concerning talent	Nieuwenhuis et al. [43]; Pienaar et al. [52]; Mohamed et al. [53]; Abbott et al. [24]
Item construction	Poor item construction with lack of theoretical framework or proper metrics Models often difficult to translate into practice	Davids et al. [5]
Tests	Invalid Yielding poor predictive value for current and future success Task designs that do not represent the performance environment	Davids et al. [5]; Pearson et al. [25]; Lidor et al. [28]
Methodology and statistics	Small random sample Sample bias as a result of the availability of subjects, motivation to participate, skill level and pre-existing properties The use of cross-sectional comparisons limits the power to predict traits associated with an athlete's long-term participation in a discipline Statistics aim to discriminate skill level as a 'function of an athlete's current achievement' Regression analysis better than discriminant function but predictive power remains insufficient Unexplained variance	Anshel and Lidor [26]; Reilly et al. [30]; Morris [72]
Athletes	Discontinuous, qualitative changes in performance due to instabilities in perceptual-motor landscape as a result of growth, development, maturation, learning, environment Many physical, physiological and psychological measures or motor skills linked to maturation	Davids et al. [5]; Matthys et al. [33, 34]; Burgess and Naughton [41]
Ethics	Procedure of selection is ethically questionable because tests exhibit false positives and false negatives while the prediction of future success remains impossible	Davids et al. [5]; Anshel and Lidor [26]

multidisciplinarity, differentiating between training effects, heritability, chronological development of characteristics and maturation seems to confront researchers with a challenging task. It is therefore not surprising that articles end with vague conclusions such as "talent scouts should have special attention for players who have quick feet" (p. 333; [34]). Finally, the procedure of a TI-based selection remains ethically questionable because the applied tests and the unreliable extrapolation of future success exhibit false positives and false negatives.

3 Genetic Identification of Talent

Genetic tests determine DNA variants (polymorphisms) that are directly or indirectly associated with the disposition for sports-related skills. The predispositions internalised in the genotype are manifested in the phenotype 'body and athletic performance'. Because genetic make-up hardly changes over the lifetime, GT might theoretically be applied irrespective of time and place, with its results being independent of an athlete's age, training cycle, daily physical state or health. From a governing body's or club's perspective, gene-based talent selection would realise a maximum utilisation of economic resources. It seemed that a single GT achieved the multidimensionality required for TI, providing sport specialists with something that is typically not achieved by applying conventional TI—a plain probability that a person with a certain genetic trait may once belong to a pool of reference elite athletes. However, the following section will show why GT is not a simplistic all-or-nothing design that helps find a talent in sport (summarised in Table 2).

3.1 Approaches to Quantify Genetic Contributions to Talent

To investigate the genetic basis of traits such as performance phenotypes and related characteristics, two basic approaches have been used.

Table 2 Deficiencies and limitations of genetic testing concerning various methodological and ethical aspects

Aspects of genetic testing	Deficiencies and limitations	References
Basic constructs	'Talent' or 'elite athlete' either not defined or defined inexactly or arbitrarily	Di Cagno et al. [93]; Ahmetov et al. [94]
	Phenotype 'body and athletic performance' difficult to outline	
Items: phenotype, genotype	Phenotype = complex, quantitative trait	Ehlert et al. [75]; Hirschhorn and Daly [79]; Frazer et al. [81]; Dewey et al. [82]; Metzker [98]; Ng et al. [99]
	Genotype = millions of SNPs and SVs matching the reference genome + non-synonymous rare or novel SNPs; SVs identified and characterised inaccurately	
Tests	Tests refer to basic abilities, investigation of traits of complex skills is difficult	Peeters et al. [74]; Frazer et al. [81]; Lippi et al. [92]
	Family studies: generational differences due to age-specific genetic and environmental effects	
	Association studies: quantitative traits with unknown variants as well as numbers of and associations between variants, unknown associations between traits	
Methodology and statistics	Small random sample	Frazer et al. [81]; Dewey et al. [82]; Yang et al. [83]; Metzker [98]
	Sample bias as a result of the availability of subjects, motivation to participate, skill level and pre-existing properties	
	100,000 individuals only yield low variance, missing heritability	
	Discrepancies between dbSNP databases; limited sensitivity and specificity of algorithms for correlation structures	
	Limited statistical power for small gene–gene and gene–environment interactions	
Ethics	Early point in time of testing might indicate that children do not understand the extent of information that can be derived from genetic tests such as disease risk	Roth [27]; Miah and Rich [108]; Williams and Wackerhage [110]
	Delivery of sensitive results	

SNPs single-nucleotide polymorphisms, *SVs* structural variants

The first type comprises heritability studies (family and twin studies) as a top-down approach without measuring genotypes. Heritability refers to the proportion of the total variation of a trait that can be attributed to genetic effects [74]. Simplified, the genetic variance includes all inherited traits and traits that cannot be modified by external influences, while the rest of the total variance depends on environmental factors [75]. A more detailed model takes into account additive and dominance genetic variance, gene–gene interactions, environmental variance and genotype–environment interaction [76].

Based on this biometrical theory, heritability studies analyse the distributions of measures in related individuals (between parents and their offspring, siblings or mono- and dizygotic twins) to statistically quantify the genetic influences on a phenotype. Family studies investigate the similarities, permitting the identification of genetic and cultural transmission of traits and maximum estimates of heritability. However, the complexity of these analyses lies in generational differences implying age-specific genetic and environmental effects [74].

Heritability studies in performance-related issues found that most of the traits accounted for 15–65 % of the total variance [77, 78], indicating small to moderate genetic influences [27]. Even genome-wide association (GWA) studies showed that in any complex trait each genomic marker has less impact on the total heritability than was expected [79–81]. Thus, the problem of the 'missing heritability' that researchers hoped would be solved by whole genome analyses still remains evident [82–84]. Frazer et al. [81] reviewed GWA studies that identified 18 genomic intervals associated with an increased risk of type 2 diabetes, accounting for less than 4 % of the total heritability. They suggested that for the explanation of a 40 % heritability, depending on their effect and frequency across the genome, ~85–800 genetic variants would be required. Based on these calculations, the significance of performance-related heritability studies must be seriously questioned, because (i) finding 800 genetic variants related to world-class sport-specific performance seems impossible, and (ii) even if 800 genetic variants were found, a 40 % heritability would not provide a sensitive basis for TI.

The second approach to study the genetic basis of phenotypes involves association or linkage studies as a bottom-up design, where a certain phenotype, for instance body height, is matched to a genetic variant [85]. Association studies investigate whether single-locus alleles or multilocus haplotype frequencies differ between two groups of individuals, such as diseased subjects and healthy controls or athletes and people who have trained and failed to reach a high level in sport. Variants in the human genome associated with different phenotypes are referred to as common or rare variants, or single-nucleotide polymorphisms (SNPs) or structural variants (SVs), depending on their dimension and frequency [81, 86]. Common variants are defined as having an allele frequency of at least 1 %, whereas rare variants show a frequency <1 % in the human population [81]. In SNPs, a single nucleotide in the genome differs compared with the human reference genome, while SVs are defined as rearrangements >1 kb [79].

Initial association studies on the 'performance phenotype' identified isolated determinants of sport performance [87–89]. Until 2009, 249 genes with sport-scientific relevance, such as the maximum oxygen uptake, anaerobic capacity, maximum sprint speed, force capability, muscle fibre type distribution, muscle enzyme levels and the trainability of some of these factors, were listed in the human gene map for fitness- and performance-related traits [90]. Early criticism had been expressed concerning weak inclusion criteria, failure of corrections due to refutations of the listed associations [91], limited relationships of some parameters to sporting performance and their limitations to certain ethnic groups [92].

It is now known that the genetic encoding of athletic performance and its determinants are polygenic. Many biological traits show continuous variation (such as height or body mass index), instead of falling into distinct categories, and are thus termed quantitative traits. The genetic basis generally involves a complex architecture of the phenotype due to the different numbers of genetic variants influencing the trait, their allele frequencies, effect sizes and multiple gene–gene and gene–environment interactions [75, 79, 81]. Nevertheless, recently published studies still investigated single gene variants [93–95]. For instance, Di Cagno et al. [93] screened elite- versus middle-level rhythmic gymnasts (as stated for conventional TI, how to standardise classification into performance levels in genetic research should be reconsidered) for the *ACE* gene because the ACE D allele has been associated with sprint and power performance. The results gave evidence of the D allele and DD genotype being more frequent in elite athletes. The authors concluded that the ACE D allele genotype could be a contributing factor to high-performance rhythmic gymnastics that should be considered in athlete development and could help to identify which skills should be trained for talent promotion [93].

Since the start of early association studies, many technical efforts have been achieved in the field of genotyping approaches, initiating an even broader field of possibilities but also pointing out further barriers.

The first reference versions of the human genome were published in 2001 [96, 97]. Because these reference sequences were either a consensus from several individuals or derived from a single person, they represent only a very small sampling of human genetic variation [82]. However, comparisons of individual complete genome sequences with the reference genome identified at least 3.2 million SNPs and up to over 900,000 SV matches [85, 98], while a further 200–500 non-synonymous rare or novel SNPs were expected [99]. Finally, the overall challenge remains—the verification of which of the variants account for or underlie the inherited constituents of phenotypes [81].

3.2 Technical Aspects and Shortcomings of Genetic Testing (GT)

The technique identifying the base sequence of a genome is termed 'whole genome sequencing'. It covers the complete range of coding and non-coding variants of human genomes and tests common and rare variants without prior knowledge of a certain gene. By generating up to billions of short sequences per run and subsequent alignment with the reference genome, information on alternative splicing and sequence variation in identified genes are provided [82, 98]. Reference sequence data can be derived from various dbSNP databases, which contain most of the SNPs estimated to exist in the human genome [100]. The final output of whole genome sequencing is a list of genotypes for positions with at least one allele differing from the reference sequence [82]. This seems to work well with SNPs but it remains difficult for SVs and their association with complex traits because sometimes SVs do not change the copy number of the affected chromosomal region [81, 82]. Although they constitute only 0.5–1 % of the genome, SVs are supposed to account for at least 20 % of all genetic variants in humans and thus might play a profound part in phenotypic diversity between individuals, or in Mendelian or complex diseases [81]. Because the reference sequence represents a small sampling of human genetic variation, it might furthermore comprise the same allele predisposition to a trait (disease) as the subject being analysed. Thus, it might not appear in the list as a variant, potentially leading to an underestimation or misinterpretation of the impact of a disease-associated allele [82]. Given the further discrepancies between several databases in terms of template size and construct, read-length, throughput and accuracy in base and genome coverage, and the difficulties of whole genome sequencing approaches in accurately identifying and characterising SVs, the broad applicability of these techniques remains limited in TI [81, 82, 98].

Human GWA studies aim to catalogue SNPs and SVs and their causal genetic variants or phenotypic differences [79, 98], identifying statistical associations between genomic intervals and common complex traits without assumptions about the genomic location of the causal variants [79, 81]. GWA studies have been successfully used to identify genes underlying monogenic Mendelian diseases with extreme phenotypic manifestations [79, 101]. Because phenotypes for sport performance are complex, individually differing and not classifiable as 'extreme' (like phenotypes of Mendelian diseases), conclusions on causal attributions will be challenging. To present some findings in the field of exercise, Bouchard et al. [102] identified 21 of 324,611 SNPs that accounted for 49 % of the response of VO_{2max} to aerobic training. Individuals showing at least 19 SNPs yielded a threefold greater increase in VO_{2max} compared with subjects with nine or less SNPs. An et al. [103] identified three quantitative trait loci (QTL) for glucose and insulin metabolism phenotypes in response to endurance exercise training, and one QTL for resting heart rate variation at baseline and in response to regular training. However, for complex diseases it is assumed that the biological explanation of the causal attribution of genomic intervals in the traits remains unreliable because alleles underlying complex traits exhibit slighter effects on disease risk and might include non-coding regulatory variants with modest impact on the gene expression [79–82]. Modest associations between common variants and common diseases were hypothesised to be mediated by weak-linkage disequilibrium between common marker variants and rare causative variants of large effect [84]. Analyses of 20,000–40,000 samples for lipid phenotypes and height identified only a small proportion of trait variance (5–10 %), leading to the conclusion that GWA studies on 60,000–100,000 individuals might explain 10–15 % of the genetic variance underlying any phenotype [81]. With respect to talent research, approximately 100,000 elite athletes from a defined discipline would be required for GT to explain an ~15 % variance of the phenotype of 'being a talent' or 'being elite' in this discipline. Based on this recognition, the utility of GT for TI becomes questionable. First, the variance of a maximum of 15 % is not satisfactory to build the basis of TI or (de)selection. Second, no defined discipline has 100,000 elite athletes (or talents). Third, even if hundreds of thousands of elite athletes existed, the selection of these 'elites' from the pool of all athletes in a discipline still requires the definition and assignment of the phenotype of being 'elite' and the knowledge of where to draw the line between 'elite' and 'non-elite'. This attribution still remains challenging.

Furthermore, all information derived from GWA studies is a statistical value describing the association of an SNP in a correlation structure (or linkage disequilibrium) with the trait. The statistical models, such as analysis of (co)variance, attempt to map the QTL underlying a complex dynamic trait by identification and separation of genetic and environmental effects on quantitative traits [104]. The specificity and sensitivity of several algorithms for predicting variant effects have been rated as being limited, showing a low correlation between predictors from the various algorithms [82]. This might be explained by the fact that GWA studies do not capture rare variants and show limited statistical power for small gene–gene and gene–environment interactions. The scientific understanding of the mechanisms underlying these interactions is incomplete, and thus an accurate model to identify and measure their effects in complex traits in humans from GWA data is lacking [81, 105].

In spite of all of the aforementioned aspects, 'genetic performance tests', such as the 'GenEffect SPORT' (GenEffect®, Fockendorf, Germany), are still available for private use and seem to find broad usage in the US and Asia [27, 106]. These tests affirm to provide information on the genetically determined predisposition for a certain sport based on the DNA screening of one or several single genes. The company, GenEffect®, claims that screening the *ACTN3* gene indicates whether a person 'is made' for sprint, power and strength sport (RR genotype), endurance sport (XX) or mixed pattern sports (RX), although this clear classification has never been demonstrated. Ahmetov et al. [94] recently published data on Russian endurance athletes who mostly carried the RR or RX genotypes instead of the supposed XX genotype for endurance performance. Considering that such companies select genes of uncertain scientific value [27, 107] and weak explanation of variance [27, 77, 78], and that data being collected from adult high-class athletes may not be transferrable to children, Camporesi [106] reasonably called these tests 'preposterous' (p. 4).

3.3 Ethical Concerns Regarding GT

Finally, not only do the technical deficiencies of GT currently appear to be paradoxical, there are also unsolved ethical issues militating against the application of GT for talent search. In spite of their shortcomings, genetic performance tests are supported effectively in the media. The promotion illustrates that DNA screening is already applicable in the embryonic stage. Therefore, genetic tests can be seen as the 'latest tool' for parents to pilot their children's future to an early entrance into professional athletics [27, 106] (whether the children like sports or not). Otherwise, a child being tested negatively for its favourite sport would be excluded from further promotion, even if it willed to train hard. According to ethical standards, these facts reflect a sensitive violation of a person's autonomy [108]. Further problems arise when a child is genetically tested without full understanding or consent [109, 110]. In particular, whole genome sequencing might simultaneously provide extensive information about disease risk, leading to the question as to whom the results of a genetic test should be provided [27, 109]. Moreover, Williams and Folland [89] illustrated the ethical problem of selection by excluding or including athletes from or in professional sports based on 'less or more proper genetic equipment'; regarding 23 polymorphisms associated with endurance capacity, the probability of the existence of a single person in the world with the 'optimal' genotype for endurance sports was calculated at 0.0005 %. Consequently, the probability of the occurrence of the worst combination of polymorphisms is equally small, while all individuals exhibit any genotype lying somewhere in the middle of the best and the worst combination.

4 Discussion

Defining talent has been shown to be difficult. One might argue that the primary aim of TI lies in finding a future top performer, while the question of whether talent in sport is innate or not is secondary. However, this question constitutes the starting point of TI and the target variable of testing. Who breaks world records and thus needs to be selected? Is it an athlete whose outstanding abilities are predicated on his genetic make-up, one who exhibits an above-average response to training or one who receives the best combination of promotion factors?

Figure 1 summarises the critical aspects evident in TI, raising the apprehension that these questions might never be answered:

Although authors tried to avoid the term talent (as an indefinite target variable) by differentiating between elite or successful and not elite or unsuccessful athletes [43, 52, 53], the classification into performance levels still requires tangible criteria. These criteria remain hard to define and therefore should gain more attention in talent research. At the current state of research, ethical concerns rise regarding the legitimacy of the process of selection. While the aim of discrimination by itself is ethically objectionable, the concerns increase if the implemented tests poorly meet the quality criteria [24]. The more false-negative results, the more potential top athletes become excluded from the systematic promotion. The prevailing deficiencies can be mirrored by citing Hoare [36], who compared rankings of basketball players by Z transformation of the results of an 'Intensive Training Centre test battery' with coach rankings. She positively concluded that "There was good alignment (…) on 60 % of occasions" (p. 404), but seemed to ignore the fact that nearly half of the rankings were inconsistent. Tromp et al. [68] recently confirmed that expert observers disagreed on the abilities of ~40 % of the junior ice hockey players in the Bantam League. Therefore, the validity of each ranking procedure should be scrutinised. Another ethical or philosophical concern pertains to the Gatekeeper Syndrome, questioning who might exhibit the right to have the final decision in selecting 'predestinated' future top athletes [26].

The talent debate has raised two research directions dealing with either conventional sports practical or GT that both continue to develop in parallel. Figure 1 depicts several paralleled limitations that never seem to be considered together. Pointing out these parallels will show that, in particular, the high-technology approaches of GT will not fill the gaps of TI and vice versa. One essential identical limitation is the low variance of approximately 60 % each of them is able to explain. Furthermore, both approaches mainly used cross-sectional instead of longitudinal test designs, leaving conclusions on developmental aspects such as influences of training on the personality, anticipation, and sport-specific techniques or epigenetic modifications open [24, 30, 40]. The sports practical test designs were assumed to assess only small numbers of weighted, isolated variables that are rarely associated with the final performance and lack a principle theoretical basis for the interrelations between expertise and talent or an athlete's development [5]. The reductionist trend underlines the lack of proper test designs and metrics. A conventional test design should rather comprise valid and reliable measurement of tasks representing the affordances of the whole performance pattern [5], such as a game-inclusive approach in team sports [41]. The current state of the art in GT only ensures assessment of basic exercise performances such as endurance or strength capabilities instead of complex skills such as shooting techniques. The establishment of representative test designs and metrics therefore remains the primary challenge in both approaches. However, the nature of complex skills indicates lower levels of reliability and validity of complex skill tests with respect to data quality and control, casting doubt upon their interpretation and scientific value.

Regarding the point in time for testing, the outcomes of the conventional TI directly depend on the biological development that codetermines anthropometrics, behavioural and motor abilities [24, 26, 62] and cannot sufficiently be captured by occasional surveys. Even if only one component showed a delay in its development or a minimal progression, it might either act as the limiting factor impeding other components in their self-organisation or lead to non-linear, unforeseen development [24]. This

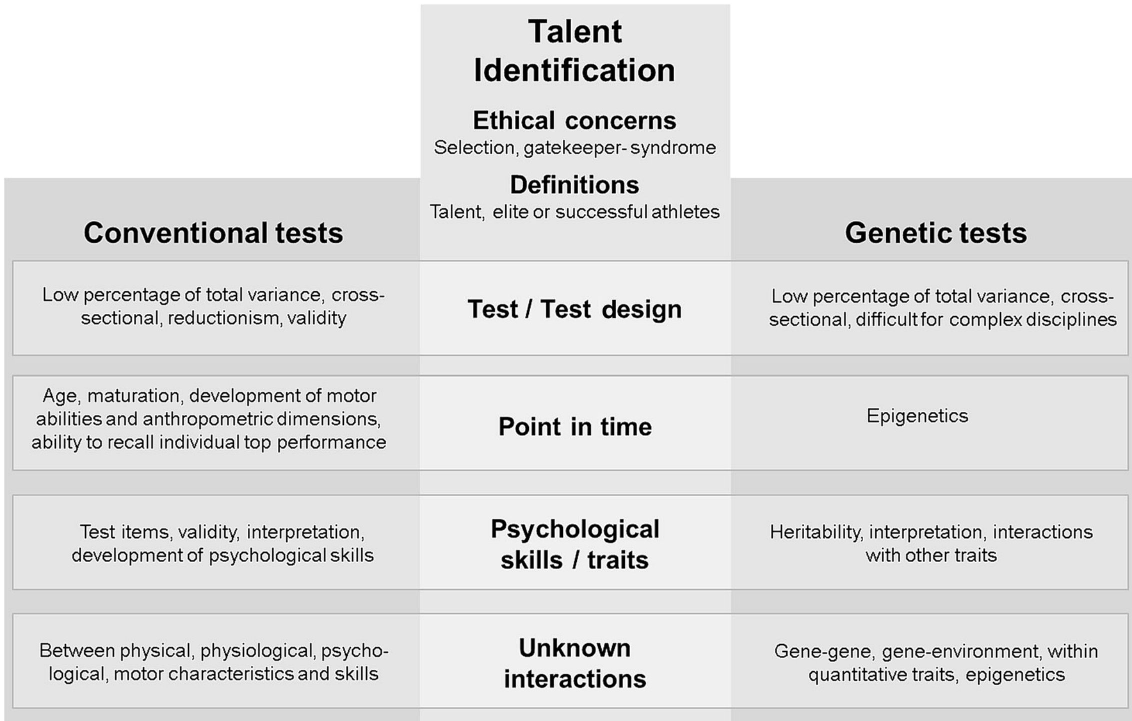

Fig. 1 Comparison of the limitations of conventional versus gene-based talent identification. General problems of talent identification reside in the difficulties of defining talent or groups of different performance levels and in ethical concerns about selection (*vertical box*). Intersections between conventional and genetic testing (*horizontal boxes*) can be summarised for aspects of the tests or test designs, the point in time of testing, psychological skills or traits and unknown interactions between different dimensions of the physique and other characteristics, or between the human genome and its environment

problem is compounded by the fact that TI aims for early specialisation, while testing children and young adolescents is accompanied by reduced validity and worse predictive accuracy. Furthermore, the true abilities of an athlete may not be assessed, if he or she is not able to recall his or her top performance in the all-or-nothing situation of testing [67]. Abbott et al. [24] argued that athletes might not exhibit direct control on random variations of behaviour in this situation. Instead, their action results from interacting environmental, organismic and task-specific constraints. Going further down to the cellular level, this action emerges from a ‘noisy’ biological system as an output of highly complex, indefinite and hardly controllable molecular processes [8]. Because epigenetic modifications remain equally uncertain [111], an independency of genetic tests from the point in time of testing, with the earliest possibility for testing in the embryonic stadium, is not to be expected. Like family studies that have been criticised for underlying unseen generational modifications [74], DNA screenings from athletes of a certain age might not be transferrable to other age groups.

To explain the difficulties in predicting future champions, it was supposed that mainly psychological variables were able to discriminate between top performers and less-skilled athletes instead of performance variables or DNA sequences encoding them [24, 36]. Previous test designs did not seem to provide an holistic profile of the psychological attributes of top performers [47]. Anshel and Lidor [26] expressed their doubts about psychological variables as discriminators due to aspects such as poor item constructions or paucity of proper psychometrics [112]. Furthermore, the development of psychological skills is linked to physical development and maturation [26, 38], devaluating again the concept of early TI. Compared with physical traits, genetic profiling of psychological traits and their projection to future characteristics are supposed to be even more difficult because the genes involved seem to underlie more complex gene–environment interactions or epigenetic modifications [27, 113, 114]. However, because research in sport psychology and genetics still exhibits operational shortcomings, the associations between both are obviously under-investigated [92]. Although heritability has been shown for exercise behaviour such as motivation to exercise [92, 115], the current capabilities are far from predicting a future top performer.

The next point addresses the unknown dependencies and interactions among the entire test items, and influences of environmental factors. For the conventional TI approach, the constitution of interactions between the physical condition in terms of developmental and training status, psychological and social factors remains difficult [3, 37–39]. Drawing detailed conclusions about single criteria of the individual capacity and its dependency or influences on other parameters might possibly become even more difficult when a multidisciplinary test battery assessed complex tasks (for example, the dependencies between ball handling and body height). Regarding GT, it can be summarised that genome-wide screenings remained meaningless unless epigenetic modifications, gene–gene and gene–environment interactions were fully captured and understood [75, 92], exercise-induced genetic regulation of proteins associated with athletic performance were identified and valid bioinformatics enabled statistical analysis of significant multilocus signals and the determination of the genetic architecture of the complex trait 'performance' [82, 92].

In addition to these parallels, each approach has recognised a crucial aspect for itself that should be discussed for the respective other one (Fig. 2).

The conventional talent research is orientating towards longitudinal test designs [34, 44, 116] and multidisciplinary testing, including assessment of tactical skills and maturational, psychological, behavioural, and sociological factors [37, 43, 117], and complex tasks instead of isolated variables [5]. Davids et al. [5] recommended test designs including 'noisy', dynamic and representative tasks with information-based control of action and continuous context-dependent deciding, allowing the recognition of individual performance solutions. In contrast, GT is still restricted to the investigation of general traits such as endurance or strength performance [92]. Being realistic, GT will never move forward to mirroring the essential multidisciplinarity. Using the newest and rapidly evolving laboratory technologies and informatics will surely provide interesting insights into molecular aspects of exercise performance, such as the association of improvements in the VO_{2max} with the SNP rs6552828 in the acyl-CoA synthase long-chain member 1 (*ACSL1*) gene, that has been shown to account for up to 6 % of the increase of VO_{2max} in response to aerobic training [102]. However, it should be excluded that individual differences in the complex movement pattern of soccer or decathlon will ever be explained by genetic variants, despite screening the whole human genome.

GT researchers therefore proposed analytical considerations concerning the feasibility of gene-based studies [79, 81] and the low probability of existing sports talents [89]. For example, Hirschhorn and Daly [79] calculated that for an allele with a frequency of 15 % and an odds ratio of 1.25, 6,000 cases and controls were needed to provide 80 % statistical power, including the analysis of 1.2–6 billion genotypes (depending on the *p*-value). Even if the costs per genome were further decreased, the feasibility of this approach would be limited due to the availability of appropriate and large athlete populations with regard to a

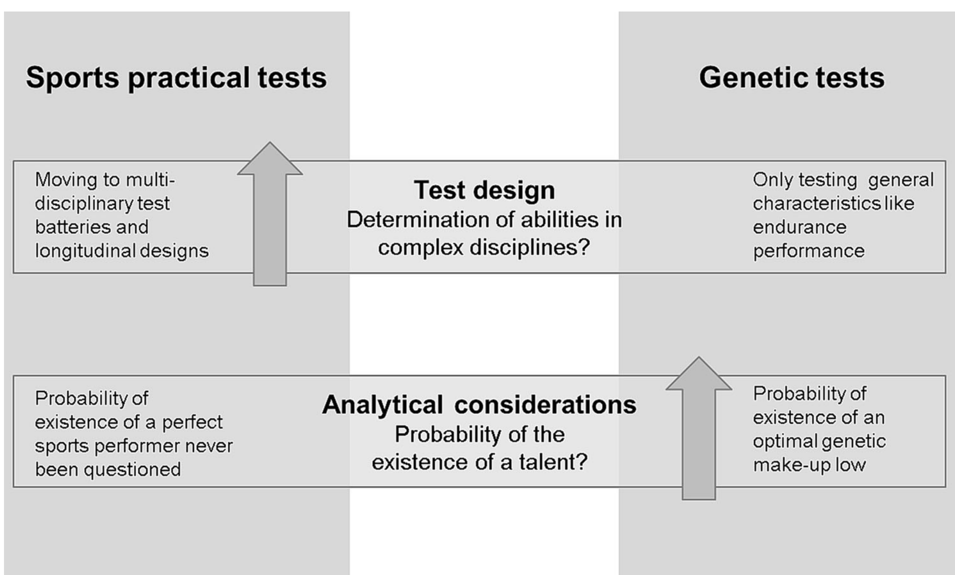

Fig. 2 Aspects of the development (*arrow*) of conventional or genetic talent identification approaches that are not considered sufficiently in the respective other approach. While the conventional talent research is paying attention to longitudinal test designs and multidisciplinary testing, the genetic testing is still restricted to the investigation of basic traits such as endurance or strength performance. Analytical considerations have been proposed within the field of genetic testing concerning the feasibility of gene-based studies and the low probability of existing sports talents. Within the conventional talent identification, analytical issues, such as considering the probability of the existence of an 'optimal' athlete exhibiting all of the required features and abilities for a certain discipline, have not been discussed in detail

homogeneous performance level and ethnicity. Lippi et al. [92] assumed that the 0.0005 % probability for the existence of an athlete carrying the 23 optimal polymorphisms for endurance performance [89] became negligible with the steadily increasing number of known variants. Within the conventional TI arena, these analytical issues have not been discussed. Hypothetically, if a test design explained 100 % of the total variance of a complex exercise task and all 'optimal' characteristics to fulfil the task were known, would the probability for the existence of an athlete with all of these characteristics exceed 0.0005 %? If two athletes exhibited 90 % of the optimal characteristics, with each 10 % deviation concerning different parameters, which athlete would be (de)selected? Who had the right to decide about that? In fact, this scenario mirrors the recent principles of TI. Furthermore, considering that 100,000 subjects are needed to explain 15 % of the total genetic variance of any phenotype [81], it might be assumed that the 60 % of total variance, which sports practical tests were calculated to account for, were overestimated due to methodological errors.

5 Conclusion

Despite the technical advancement of measuring movements and genetic dispositions, we are still facing a multitude of problems inherent in the construction and methodology of talent research and practice of identification. Finally, this review does not come down to a clear vision about how to trace (in the sense of identifying) talents in sport. It may rather point to positive developments. First, the orientation towards the approach of talent development constitutes a promising direction because it ensures a time-independent, more development-friendly promotion and a more comprehensive view on the athletes [5, 21, 24, 41]. For example, Abbott et al. [24, 118] proposed a model comprising long-term support of athletes with regular assessment of their actual proficiency and adaptation of training contents and environments. Although the tests being applied for the assessment of the actual abilities correspond to TI with the designated shortcomings, the results do not directly lead to (de)selection. Best-practice examples for the model of talent development are the American college athletics system and the Kids Clubs of the German Football Federation. Second, the ecological dynamics approach proposed by Davids et al. [5], with the aim of assessing representative performance product and process variables of the complex sport performance demanded during competition, takes into account the reductionist trend of conventional sports practical tests. However, this approach still relies on reliable and valid measurement methods of complex performances.

GT has been supposed to serve in the risk stratification for the participation in high-performance sports instead of TI [89, 109, 119, 120]. DNA analysis might prevent athletes from dying due to exercise without being aware of a serious pathological condition. It is already recommended in borderline cases of hypertrophic cardiomyopathy and required for the long QT syndrome [109]. However, with respect to the pending ethical concerns and technical and financial hurdles, a routine application of GT in the field of training and exercise remains wasteful.

In conclusion, many deficiencies in the current TI system and research have gained attention, and efforts are being made to overcome them. Future research needs to clearly define the group of interest and comprehensively implement all methodological improvement suggestions. We will have to observe how the system of athlete promotion develops. However, it always remains a challenge.

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