Talent inclusion and genetic testing in sport: A practitioner's guide

Alexander B. T. McAuley*[1], Joseph Baker[2], Kathryn Johnston[2], Ian Varley[3], Adam J. Herbert[1], Bruce Suraci[4], David C. Hughes[1], Loukia G. Tsaprouni[1], Adam L. Kelly[1]

[1] Faculty of Health, Education and Life Sciences, Birmingham City University, Birmingham, United Kingdom

[2] School of Kinesiology and Health Science, York University, Toronto, Canada

[3] Department of Sport Science, Nottingham Trent University, Nottingham, United Kingdom

[4] Academy Coaching Department, AFC Bournemouth, Bournemouth, United Kingdom

* alex_mcauley@outlook.com

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ABSTRACT

Current scientific evidence does not support the implementation of genetic tests to enhance the processes of talent identification and development systems. Regardless of this consensus, it appears likely that sport stakeholders will continue using genetic tests. This paper aimed to provide practitioners with some best practice guidelines if implementing genetic testing within their organisations. First, we assess the growth and perceived flaws of direct-to-consumer genetic testing companies targeted towards sport. The sports genomic literature is then summarised to demonstrate the lack of established genetic associations with sporting phenotypes and the prevalent limitations that exist in this field of research. Following this, examples are presented suggesting some stakeholders in sport have already used genetic tests to screen for variants associated with performance phenotypes, while the potential appeal of genetic information to sport stakeholders is also discussed. The value of increased genetic literacy (i.e., enhanced education/understanding of genetic information) is then considered, as well as the promotion of talent inclusion (i.e., using genetic tests to include or retain athletes rather than for de-selection and exclusion purposes). To conclude, we offer practitioners several recommendations and best practice guidelines with regards to the implementation of genetic testing in sport.

Keywords

athlete development, genomic, high performance, polymorphism, talent identification

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Introduction

In sports genomics, there is consensus between many research groups that the current scientific evidence base does not support the implementation of genetic tests to identify and select talent, individualise training program design, mitigate injury risk, or enhance overall athlete development processes (Tanisawa et al., 2020; Vlahovich et al., 2017; Webborn et al., 2015). However, despite the repeated caution from scientists, many sporting organisations, practitioners, and athletes appear to utilise genetic testing for such purposes (McAuley, Hughes, Tsaprouni, Varley, Suraci, Roos, et al., 2022b; Pickering & Kiely, 2021; Varley et al., 2018). This seems likely to continue as sporting stakeholders seek to gain every advantage possible in their pursuit of success, or at least ensure they do not position themselves at a competitive disadvantage by neglecting potential advances employed by their competitors (McNamee et al., 2018).

Accessibility to genetic testing also continues to improve as the number of direct-to-consumer (DTC) companies is increasing rapidly over time, alongside a significant annual decrease in the cost of genome sequencing procedures (Goodlin et al., 2015; Pickering et al., 2019). It is likely that due to the novelty of genetic testing in sport, stakeholders are vulnerable to misinformation; particularly since there are limited formal regulations, legal legislation, and best practice guidelines to follow (Patel & Varley, 2019; Webborn et al., 2015). Not only is a guidance document of best or better practices required for practitioners, there is also a need to shift the narrative regarding the utility of genetic information (Dar-Nimrod et al., 2021), and how it could (and perhaps should) be employed in sport. This is especially important because it is generally accepted by researchers that genetic testing will inevitably become commonplace in sport - despite the insufficient supporting evidence and the robustness of researchers' cautions against it at this moment in time (Vlahovich et al., 2017).

Don't do it, but if you do…

Instead of repeating these cautionary sentiments again (which we fully support), it may be useful to explore how genetic testing could be used in the most appropriate way(s) to mitigate against the associated risks considering its anticipated widespread implementation. For instance, genetic testing may benefit stakeholders involved with talent identification and development systems in sport, if implemented to promote approaches to retain or include the greatest number of high-potential athletes within these systems (i.e., for talent inclusion). In this way, genetic testing may help prevent the inappropriate early exclusion of more athletes in development pathways by alleviating some of the systemic, unconscious selection biases that exist in youth sport (e.g., advanced maturation status, relative age effects; Cumming et al., 2017; Kelly & Williams, 2020; Webdale et al., 2020).

In this paper, we begin with an assessment of DTC genetic testing companies by exploring their growth in the sport and exercise/health domains and summarise their shortcomings. This is followed by an evaluation of current scientific evidence in relation to genetic associations with phenotypes that may be relevant to practitioners in sport. We then provide examples that showcase how genetic testing has been implemented in sporting organisations over the last decade, before endeavouring to explain the allure of genetic information to stakeholders in sport. The importance of genetic literacy is then discussed, as well as the deterrence of genetic testing for de-selection and exclusion purposes. Finally, we conclude with several suggestions for practitioners moving forward and provide some best practice guidelines in relation to implementing genetic testing within sporting organisations.

Direct-to-consumer genetic testing

In 2007, the first DTC genetic testing company 23andMe (https://www.23andme.com/en-gb/) began operating (Spencer & Topol, 2019). Since then, there has been a significant increase in the number of DTC companies offering genetic testing services, with recent research suggesting there are ~70 DTC genetic testing companies marketed towards predicting sport and exercise performance (Pickering et al., 2019). This reflects the growing interest in the area from business leaders and entrepreneurs, as earlier research identified 22 in 2013 (A. G. Williams et al., 2014) and 39 in 2015 (Webborn et al., 2015). An important component of this growth is the substantial decrease in the cost of sequencing and genotyping over the last decade. For instance, whole-genome sequencing now costs less than $ 1,000 compared to ~$ 10,000 ten years ago, which is primarily due to significant advances in genomic technology (Institute, 2021). This becomes even less expensive for analyses of specific variants and is, therefore, more economically viable for prospective companies as a business venture and for coaches looking for additional information about their athletes (Webborn et al., 2015).

Increases in market competition inevitably leads to greater consumer accessibility as businesses are encouraged to reduce prices, improve product quality, and innovate by offering bespoke services to expand their market share (Becker, 2017). DTC companies attempt to make their product appealing to stakeholders in sport by using endorsements from successful current and former professional athletes. As an example, DNAfit (n.d.) male and female ambassadors include Rio Ferdinand (English international football player), Bryan Habana (South African international rugby player), Greg Rutherford (Olympic long jump champion), and Eilish McColgan (Olympic middle-distance runner). In addition, some professional sporting bodies have public affiliations with DTC companies. For instance, UK Coaching (https://www.ukcoaching.org/subscription) offers its members discounts on genetic tests supplied by the DTC company MUDHO (https://muhdo.com). This is a common marketing ploy to improve a company's reputation and subsequently increase the pool of prospective customers by taking advantage of well-known psychological phenomena (e.g., endorsement theory; Schimmelpfennig & Hunt, 2020).

With the substantial increase in DTC companies, there is a large variety of services now available to a wide range of different consumers. There are even DTC genetic testing companies that target specific sports. For example, despite providing no evidence to support their assertations, Soccer Genomics (https://www.soccergenomics.com) claim they can provide a personalised training and nutrition program designed to maximise the overall performance of footballers based on their DNA. Soccer Genomics does this by providing customers with information on which genetic variants they have, along with the variants' associations with several performance-related phenotypes (i.e., strength, speed, endurance, flexibility, and injury risk) and metabolic processes (i.e., carbohydrate and fat metabolism). However, across all these phenotypes, Soccer Genomics uses genotype data of only 14 genetic variants, and in the case of some phenotypes (e.g., strength), uses only one genetic variant when prescribing these programs to customers. In reality, it is likely these phenotypes are influenced by thousands of genetic variants (Bouchard, 2015).

Although Soccer Genomics provides customers with information about why a genetic variant may be important to each phenotype in their reports, they do not provide any scientific research supporting their claims. This makes it impossible for prospective consumers (or researchers) to independently assess the evidence base these programs are alleged to be formulated from. These issues (i.e., the use of a small number of genetic variants and a lack of transparency regarding the supporting evidence) are prevalent across DTC companies (A. G. Williams et al., 2014). Indeed, some DTC companies do not even provide information on which genetic variants they test for, possibly due to commercial sensitivity (Webborn et al., 2015). Of the DTC companies that do cite peer-reviewed research studies, these studies may reflect a cherry picking procedure to suit the marketing needs of their specific product and not represent the scientific literature as a whole (Spencer & Topol, 2019). This has led to inconsistent variant interpretations and a lack of reproducibility throughout the industry.

There are DTC companies that provide prospective customers with some information on who and how genetic testing should be used. For instance, DNAfit's (n.d.) code of practice states that genetic tests should not be provided direct to consumers under the age of 18 years, and that DTC genetic tests should never be used for talent identification or to predict sporting ability (DNAfit, n.d.). Unfortunately, this type of information and these sentiments are not universal across all DTC companies and is not explicitly made available for consumers to view before purchasing. Interestingly, another element of DNAfit's (n.d.) code of practice is that DTC companies should not make misleading claims about the potential benefits of their products. However, it is has been suggested that the very essence of DTC genetic testing companies is embodied as a faux scientific authority and manipulating consumer identify-seeking by marketing overstated genetic determinism (Caulfield & McGuire, 2012; Spencer & Topol, 2019). Some DTC companies offer customers the option of speaking with a genetic counsellor (often placed behind an additional pay wall) to help explain their results and provide context to the possible genetic associations. However, this would be an extremely difficult task and could be considered speculative work, given that DTC companies' marketing is mostly in conflict with the scientific literature.

Current scientific evidence base

Of all phenotypes of potential interest to sporting stakeholders (e.g., physiological capacity, psychological characteristics, technical capabilities, injury risk, nutritional requirements, and ergogenic aids), there are few (if any) identified genetic variants that have had their associations replicated and subsequently validated in adequately-powered studies using independent homogenous cohorts (Ahmetov et al., 2021; Guest et al., 2019; McAuley et al., 2023; McAuley, Hughes, et al., 2021b; McAuley, Hughes, Tsaprouni, Varley, Suraci, Baker, et al., 2022; McAuley, Hughes, Tsaprouni, Varley, Suraci, Roos, et al., 2022a; Varillas-Delgado et al., 2022). Of the variants that have repeatedly shown associations with performance related phenotypes (e.g., *ACTN3* R577X and *ACE* I/D polymorphisms), their effects only explain a trivial (~1%) amount of inter-individual variation (McAuley, Hughes, et al., 2021b; Papadimitriou et al., 2016). Moreover, there is very limited understanding of how genetic variants interact with each other and specific environmental exposures, as sporting phenotypes are multifactorial and likely underpinned by epigenetic mechanisms (Mattsson et al., 2016; McAuley, Baker, et al., 2021).

Due to the inconclusive evidence base regarding genetic associations with sporting phenotypes, the current consensus amongst researchers in this field is that there is insufficient scientific basis to implement genetic testing into the practical domain for any identification and performance-related purposes at this moment in time (Tanisawa et al., 2020; Vlahovich et al., 2017; Webborn et al., 2015). This is not to say that researchers should not continue to build on the current evidence base, since it is important to keep growing our knowledge in this field, which may help the implementation of genetic testing in future years to be more viable. Currently, one of the main issues limiting the quality of evidence produced in genetic association studies is sample size (Ginevičienė et al., 2022; Varillas-Delgado et al., 2022). As mentioned, individual variants generally display very modest effect sizes (e.g., odds ratio [OR] less than 1.5 and R2 less than

0.01) with polygenic (i.e., influenced by numerous genes and variants) traits such as athletic performance (Bouchard, 2015). To achieve adequate statistical power (i.e., 0.80) with an alpha level of 0.05, a cross-sectional study examining the association of one genetic variant under an additive model (i.e., A/A vs. A/a vs. a/a) with a quantitative trait (e.g., jump height) requires approximately 800-1500 athletes to identify an association that explains 0.5-1% of the variance (Bouchard, 2011; Hagberg et al., 2011). Similarly, in a case-control study examining the association of one genetic variant (with a minor allele frequency [MAF] of 0.20) under an additive model on a dichotomous trait (e.g., athlete status), approximately 1,400 athletes and 1,400 controls are required to identify an association with an OR of 1.2 (Bouchard, 2011; Hagberg et al., 2011).

Using a dominant inheritance model (A/A vs. A/a-a/a), genetic variants with higher MAF and increasing case-to-control ratio (1:4 is considered optimal) are ways to decrease athlete sample size requirements (Hong & Park, 2012). However, the samples used in sports genomic studies are still well below the minimum requirements. For example, a recent review of genetic association studies in football reported that the median sample size used was 60 (McAuley, Hughes, et al., 2021a). For samples of this size, a genetic variant studied in isolation would need to produce an OR over 2.2 for the study to be considered adequately powered, which is highly unlikely. That said, it is important to recognise that researchers should not be criticised for conducting studies with such low sample sizes. Often, there are proprietary/confidentiality concerns regarding the information that might be shared that could jeopardize a potential competitive advantage. Moreover, high-performance athletes are limited in number by their very nature (Guilherme et al., 2014). If individual studies are conservative in their inferences, acknowledge their limitations, and use transparent methodologies, they can contribute to research synthesis approaches (e.g., meta-analyses) in the future to draw more valid and reliable conclusions (Ginevičienė et al., 2022; McAuley, Baker, & Kelly, 2022).

Another strategy being employed by researchers to solve sample size limitations is the formation of international consortia to facilitate the sharing of data and resources between multiple research groups (e.g., Athlome Project Consortium, Football Gene Project; McAuley, Hughes, et al., 2021a; Pitsiladis et al., 2016). In principle, this approach to data sharing has promise if the accompanying ethical, bureaucratic, and logistical concerns can be navigated successfully. However, collaboration on this scale may also exacerbate the heterogeneity of athlete samples in terms of factors such as competitive playing level, sport discipline, geographic ancestry, on-field playing position, sex, chronological age, maturity status, and phenotype measurement. Cohort homogeneity is vitally important in sports genomic research, as each of these factors can have a confounding influence on genotype-phenotype associations (Guilherme et al., 2014; Mattsson et al., 2016; Tanisawa et al., 2020).

Bringing cohorts together from different countries also requires researchers to carefully consider what criteria should be used to categorise athletes into competitive groups (e.g., elite, sub-elite, non-elite). Sports differ in terms of popularity and development across nations, so the performance level of athletes will need to be assessed relative to the competition pool both inside and outside their own country (McAuley, Baker, & Kelly, 2022; McKay et al., 2022). Heterogenous samples and the inconsistent categorisation of elite athletes are already prevalent limitations throughout the sports genomic literature, as many studies combine athletes with distinct defining characteristics together and infer proficiency using misguided measures (Tanisawa et al., 2020; Varillas-Delgado et al., 2022). Moreover, some studies do not provide any information on the characteristics of their samples or an explicit explanation regarding athlete categorisation, which is no doubt further facilitating contentious interpretations (McAuley, Hughes, et al., 2021a). Fundamentally, DTC genetic testing companies are making speculative inferences from the results of underpowered studies comprising various uncontrolled confounding variables to overestimate and prematurely infer practical utility.

Implementation of genetic testing in sport

Despite the unequivocal disapproval of implementing genetic testing in sport by researchers at this moment in time (Vlahovich et al., 2017; Webborn et al., 2015), there are various forms of evidence suggesting genetic testing has been utilised by stakeholders in sport for several years. For instance, there have been numerous reports of genetic testing in sport via anecdotal sources. In 2005, it was reported a professional Australian rugby league team had tested 18 of its 24 players for eleven performance-related genetic variants in an effort to optimise their training programs (Dennis, 2005). In 2008, a story surfaced that a professional football club contacted a researcher about using genetic testing on players to identify if they have a predisposition for athletic excellence (Scott & Kelso, 2008). In 2012, a news article stated that the English Institute of Sport was trying to integrate genetic testing to tailor the training, conditioning, and preparation of Britain's Olympic and Paralympic athletes (Watts, 2012). A 2014 article reported that a DTC company was working with two English Premier League football teams, another football team in Europe, and a British Olympic athlete to individualise training programs based on 45 genetic variants (Williamson, 2014). In 2016, reports suggested FC Barcelona were also testing their players for 45 genetic variants to estimate their injury susceptibility (Miller, 2016). In 2018, an article was published on the partnership between a DTC company and the Egyptian Football Association and Egyptian Olympic Committee to use genetic testing to report on variants relating to fitness and nutrition to prepare their athletes for the 2018 FIFA World Cup and 2020 Olympic Games (Holmes, 2018). Most recently, reports suggest China implemented genetic testing during their athlete selection process ahead of the 2022 Winter Olympic Games (Haff, 2019). Collectively, these examples of professional sporting organisations in the public domain may make genetic testing even more appealing to consumers.

There is also empirical evidence of genetic testing being implemented in sport throughout the scientific literature. Specifically, research groups have conducted surveys in recent years aimed towards revealing to what extent genetic testing has been utilised by stakeholders within sport. For instance, in 2018, researchers investigated the prevalence of genetic testing across multiple sports in the UK, reporting that 17% of the 72 high-performance athletes and 8% of the 95 support staff who responded to their survey indicated they have used genetic testing (Varley et al., 2018). In 2021, another research group examined the frequency of genetic testing across multiple sports and performance levels in different countries, reporting that 10% of the 110 athletes and 11% of the 133 support staff who responded to their survey revealed they had used genetic testing (Pickering & Kiely, 2021). More recently, researchers exploring the extent of genetic testing in professional football reported that 10% of the 122 coaches, practitioners, and players who responded to their survey indicated they personally had used genetic testing, whereas 14% stated their organisations used genetic testing (McAuley, Hughes, Tsaprouni, Varley, Suraci, Roos, et al., 2022b). Although limited, taken together these studies suggest genetic testing is currently being used by athletes and practitioners, and has been implemented by organisations across different sporting contexts.

Explaining the allure of genetic testing

From a DTC company perspective, there are clear commercial pressures to sell services that can result in the exploitation of data that has limited scientific support (Tanisawa et al., 2020). These pressures are not limited to DTC companies, as stakeholders across all levels of sport face similar burdens and demanding expectations on a continual basis. This has resulted in sport stakeholders traditionally searching for innovative approaches and novel tools to gain a competitive edge, or at the very least, not fall behind contemporary advances of their competitors (McNamee et al., 2018). One of the principal challenges sporting organisations and coaches struggle with is improving predictions of athletes' potential to achieve expertise at early stages of development.

Conventional talent identification models and prediction methods are considered unreliable, as they generally have poor accuracy that only decreases further when conducted with younger age groups (Farah & Baker, 2021; Koz et al., 2012; Till & Baker, 2020). For instance, a recent systematic review of the efficacy of North American major professional sport draft systems, found that draft decisions were most effective at predicting future success in the first rounds, but had questionable accuracy in the majority of rounds thereafter (Johnston & Baker, 2022). These selection errors are costly from an organisational standpoint (e.g., inefficient allocation of resources, diminished recruitment options) and have negative repercussions for athletes (e.g., compromised development, reduced prospects), which can result in unfulfilled potential (Johnston et al., 2021; Johnston & Baker, 2020).

Predicting the potential of athletes to achieve expertise in their sport domain is a difficult task for decision makers at clubs and organisations due to the dynamic nature of talent and evolution of sport over time, which is further compounded by system constraints (e.g., budget limitations, strict timelines, regimented policies; Den Hartigh et al., 2018; Johnston & Baker, 2020; Sieghartsleitner et al., 2019; Till & Baker, 2020). At present, there appears to be a reliance on static, objective measurements at one-off timepoints and subjective preferences based on intuition/gut-instinct (i.e., coach's eye; Johnston et al., 2018, 2021). Currently employed activities have been described as performance identification, since selectors are evaluating athletes on existing performance levels and not necessarily future developmental potential (Baker et al., 2018). This approach prioritises (and undoubtedly achieves) short-term objectives of talent systems (i.e., winning at youth level) but ultimately undermines long-term aims (e.g., producing high-performance senior athletes; Till & Baker, 2020).

A general result from current practices is that they create biased contexts where advanced growth and maturation and being relatively older (i.e., relative age effects) are advantageous (Johnston et al., 2018; Kelly & Williams, 2020; Sarmento et al., 2018). Moreover, selectors are potentially subject to a wide range of cognitive biases (e.g., confirmation bias, endowment effect, primacy effect, sunk-cost fallacy) that unconsciously influence their decision-making processes and may contribute to prediction fallibilities when judging athlete potential (see Johnston & Baker, 2020 for a review). Attempts are on-going to decrease the prevalence of maturation (Cumming et al., 2017) and relative age (Webdale et al., 2020) biases, and to better understand the variables and explicit criteria that selectors use during their subjective decision-making processes (Johnston & Baker, 2022; Lath et al., 2021; Roberts et al., 2021). Although these are still at an early stage, some progress is being made (Kelly et al., 2021).

Utilising genetic information may be viewed by stakeholders in sport as an attractive solution or improvement to these conventional talent identification methods based on material presented by mainstream media sources and educational systems. It has been suggested by some researchers that a false narrative has been generated by these social agents through an emphasis on oversimplified one gene, one disease accounts (Dar-Nimrod et al., 2021). Moreover, these accounts are communicated with an erroneous, fatalistic flair that facilitates misconceptions and genetic essentialism (i.e., the tendency to think of genes as a defining immutable feature, encompassing one's essence, making people who they are, and who they are going to be; Dar-Nimrod et al., 2021). For instance, deterministic newspaper articles (e.g., Fat gene found by scientists; Henderson, 2007), blockbuster movies (e.g., GATTACA), and educational curricula within schools focusing on Mendelian inheritance are simple to digest, but may exacerbate reductionist philosophies through psychological priming (i.e., exposure to a specific stimulus unconsciously influences responses to subsequent related stimuli; Donovan et al., 2021; Heine et al., 2017). Indeed, research quantifying genetic literacy within and across populations around the world has found that in general, knowledge is poor, and a large proportion of the population holds incorrect beliefs (Dar-Nimrod et al., 2021). This was exemplified in a recent survey of stakeholders in professional football, whereby over one third of sampled participants believed genetic testing currently has great utility in sport and should be used for talent identification and athlete selection (McAuley, Hughes, Tsaprouni, Varley, Suraci, Roos, et al., 2022b). Moreover, the majority (~90%) of these stakeholders believed they had insufficient genetic knowledge to make an informed decision regarding genetic testing, as well as felt that genetic research is currently not communicated effectively with stakeholders.

Genetic literacy and talent inclusion

The misunderstanding of genetic information is of concern as it can have a profound impact on important sporting choices. Indeed, genetic essentialism may hold negative consequences as beliefs about the inherent origin of talent affect individuals' behaviour, motivation, and performance (Hancock et al., 2013; Johnston & Baker, 2020). For athletes, this may reflect their willingness to train, level of effort, and response to failure, whereas in coaches, this may reflect their attentiveness, patience, and time dedicated to the development of individual athletes (Baker et al., 2018). Ultimately, rigid genetic essentialist thinking (coupled with such deterministic beliefs) would further compromise talent identification and development systems, by diminishing the important role of environmental factors and neglecting the dynamic nature of talent (McAuley, Baker, et al., 2021). This would foster unrealistic expectations of higher performing athletes at early ages, as well as potentially limit the opportunities of athletes who have a higher peak performance capacity and long-term potential to achieve expertise but require a longer developmental timeframe (e.g., athlete D in Figure 1).

Fortunately, research indicates increasing genetic literacy is a potential remedy to essentialist and deterministic beliefs (Donovan et al., 2021). Moreover, sporting stakeholders have expressed a desire to learn more about genetic research and are open to educational interventions (McAuley, Hughes, Tsaprouni, Varley, Suraci, Roos, et al., 2022b). However, it is important to note that educational interventions must be tailored specifically towards decreasing genetic essentialism beliefs (e.g., focusing on polygenic traits and gene-environment interactions), as an increase in general genetic knowledge does not always lead to reductions in genetic determinism, possibly due to confirmation bias (Dar-Nimrod et al., 2021; Donovan et al., 2021). Altering pre-existing essentialist beliefs and educating stakeholders in sport on the utility and nuances of genetic information is likely to take some time. In the interim, since genetic testing is already being implemented within sporting organisations, it may be useful to encourage stakeholders to use genetic information in a more appropriate manner.

Of immediate importance is the deterrence of genetic testing for de-selection/exclusion purposes. Whilst there is limited evidence organisations are currently using genetic testing for these purposes (Haff, 2019; Scott & Kelso, 2008), empirical studies have reported between 35% (McAuley, Hughes, Tsaprouni, Varley, Suraci, Roos, et al., 2022b) and 67% (Varley et al., 2018) of surveyed stakeholders in sport believe genetic testing should be used for talent identification. It has been proposed (see Baker et al., 2018; Till & Baker, 2020) that too many young athletes are already incorrectly excluded from development systems due to inaccurate predictive models. By adding another method of (de)selection to the equation (and a poorly understood one at that), the waters become even murkier. Instead, if decision makers are intent on implementing genetic testing within their talent identification and development systems, this should only

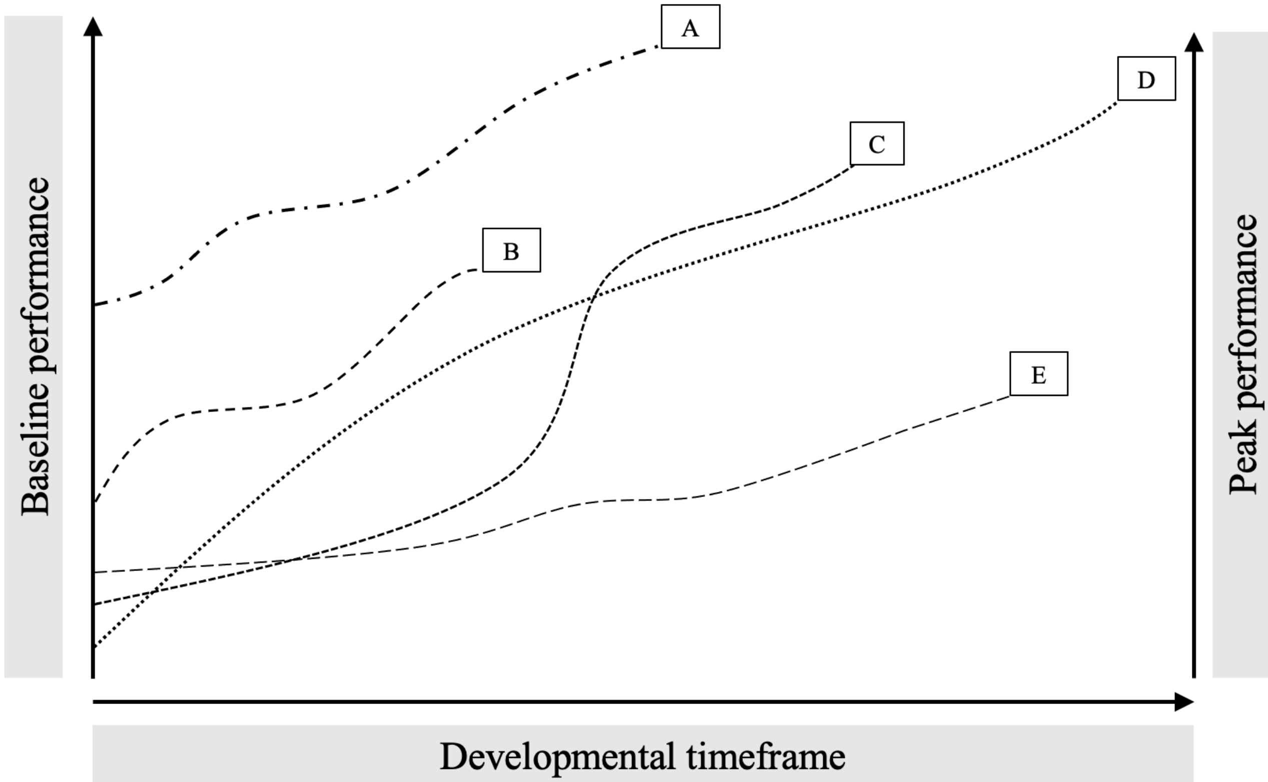

Figure 1 Inter-individual variation in baseline performance, developmental timeframe, and peak performance. Letters A, B, C, D, and E within the square boxes represent different athletes. The adjoined lines illustrate athletes' baseline and peak performance levels, as well as the length of their non-linear developmental timeframe. As an example, a clear distinction exists between athlete A and athlete E, whereby athlete A has higher baseline and peak performance levels and has a shorter developmental timeframe than athlete E. In comparison, a more intricate distinction exists between athlete B and athlete D. Whilst athlete B has higher baseline performance and a short developmental timeframe, athlete D has the capacity for higher peak performance but requires a longer developmental timeframe.

be to promote talent inclusion. As mentioned, talent inclusion refers to the practice of including or retaining the utmost number of potential talents within identification and development systems based on any conceivable predictive metric. In practice, this would represent including an athlete with a high polygenic score (i.e., a possible advantageous genetic profile) who otherwise would have been excluded based on performance assessments. This may be particularly valuable with regards to athletes who currently display poor performance levels but have great developmental potential, as arguably these athletes are at a greater risk of de-selection due to the performance-based nature of selection systems (see Figure 2).

This practice would align with the aims of organisations orientated towards accepting type 1 errors (false positives) over type 2 errors (false negatives). Retaining more athletes may have accompanying financial consequences that would require more efficient management and allocation of resources, which may deter organisations (Till & Baker, 2020). However, there have been long-standing calls to change the structure of athlete development systems to facilitate an increase

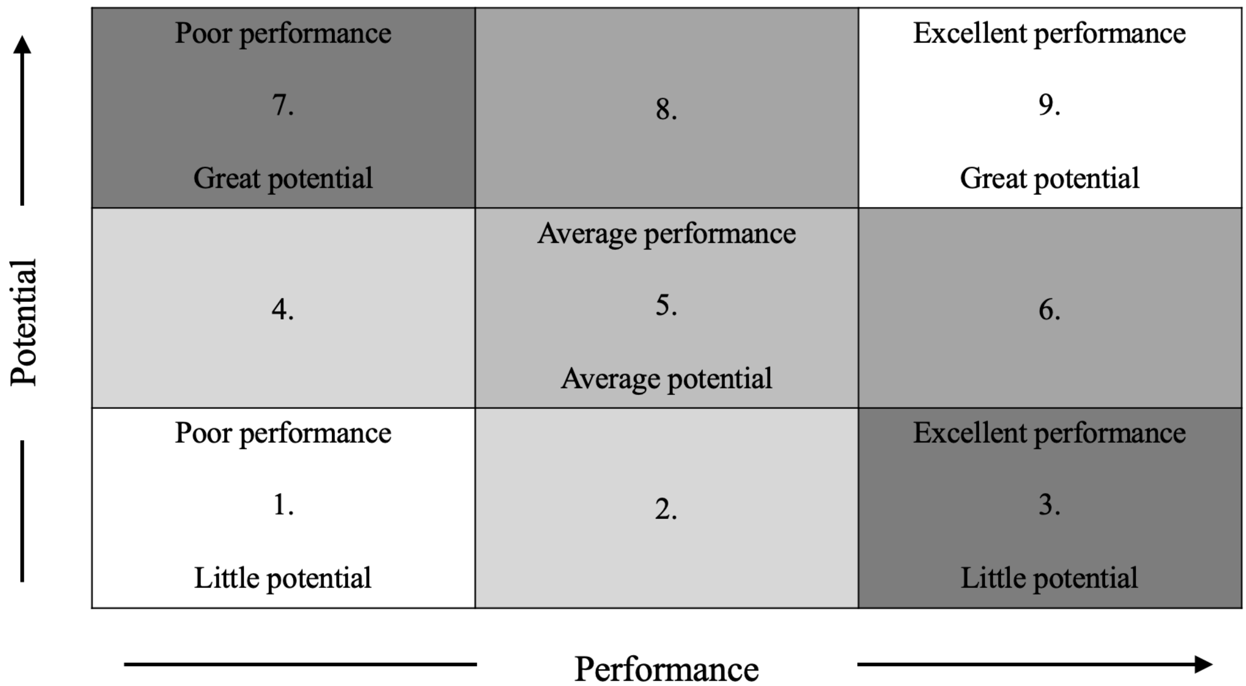

Figure 2 Talent identification/selection risk matrix adapted from Baker et al. (2018). In this model, performance represents athletes' ability at a static, one-off timepoint, whereas potential represents athletes' future developmental capacity. Areas with lighter shading represent a lower risk of an inaccurate decision, whereas areas with darker shading represent a higher risk of an inaccurate decision due to the performance-based nature of selection systems. Decision makers within talent identification and development systems may find this to be a useful tool to determine the level of risk for each athlete being evaluated by considering both current performance and future developmental potential.

in the initial number of potential talents and the minimum amount of time they are included in developmental programming. Indeed, delaying identification/selection and widening development opportunities has been recommended for over a decade by leaders in this field (e.g., Baker et al., 2009; Cobley et al., 2009), and is now implemented in some sports successfully such as rugby (Till & Baker, 2020). Moreover, it may be more cost-effective and rewarding for organisations in the long-term to prioritise dedicating their financial resources to including/retaining more athletes, than purchasing genetic products with questionable validity on a yearly basis as minor inconsequential discoveries are made.

Moving forward and practitioner guidelines

In the future, it is likely additional genetic variants will be discovered and incorporated into polygenic profiling tools with more accurate weightings to enhance prognostic capabilities (Pickering et al., 2019). As these significant genomic advances are made, genetic information may have more utility in sport, but not necessarily for talent identification. All human traits are thought to be influenced by genetic factors, although there is considerable between-trait-variance in heritability estimates (Polderman et al., 2015). Moreover, nearly all traits are complex (i.e., influenced by more than one gene) and even those with high heritability are still influenced by a very large number of genetic variants. For instance, height has a heritability estimate of 80% and has been associated with over 3,000 genetic variants, which still only explains ~25% of inter-individual variance (Yengo et al., 2018).

As discussed, athletic performance is a complex trait underpinned by a multitude of other complex traits, each regulated by an intricate network of interconnected biological pathways and independently influenced by environmental exposures (McAuley, Baker, et al., 2021; Tucker & Collins, 2012). In addition, the degeneracy of biological systems (i.e., structurally different elements performing similar functions; Davids & Baker, 2007) and compensatory nature of athlete development (i.e., weaknesses in some attributes compensated by strengths in others; Baker et al., 2019; A. M. Williams & Ericsson, 2005), coupled with the characteristics that encompass optimal performance changing over time (Baker et al., 2019), means distinct genetic profiles will likely be associated with expertise in the sporting domain. Moreover, will these genetic profiles ever be predictive *a-priori* based on evidence-driven analyses and not just *a-posteriori* as a result of data-driven analyses? This is before considering simple serendipity (i.e., low probability events). Overall, athletic performance is a qualitative phenotype, not a physiological measurement (Mattsson et al., 2016).

Practitioners are encouraged to utilise research that has established genetic associations with specific physiological, psychological, and injury traits to improve athlete development (e.g., modify training interventions to elicit optimal adaptations, manage athlete welfare, and reduce injury susceptibility). However, practitioners should always remember that genetic information should not be used in an isolated deterministic manner, but rather as an additional objective tool that may help with subjective development decisions; similar to how anthropometric measures, fitness tests, performance analysis statistics, and psychological profiles are currently used (McAuley, Baker, et al., 2021). It has also been proposed that genetic testing may aid in screening young athletes for risk of cardiomyopathies (e.g., hypertrophic cardiomyopathy) and channelopathies (e.g., congenital long-QT syndrome), which are major causes of sudden cardiac death (Barretta et al., 2020; Tanisawa et al., 2020). Genetic information itself should not be feared, however, fears regarding deterministic misunderstandings and reductionist applications are warranted. Arguably, genetic elements are already entrenched within development systems in terms of bio-banding, which relies on the heredity of parental height (Cumming et al., 2017).

Even if the complexity of processes such as epistasis/emergenesis (i.e., gene-gene interactions) are fully untangled, environmental contingencies can always alter phenotype outcomes as no trait is 100% heritable (Polderman et al., 2015). Genetic information is simply one piece of the developmental puzzle within a holistic bioecological approach (i.e., an additional column in an athlete profile spreadsheet). There are still appropriate concerns with regards to the area of the genome screened in genetic tests, as some genetic variants could reveal serious health conditions, not only of the athlete but of immediate family members (e.g., cystic fibrosis, Huntington's disease, sickle cell anaemia; Tanisawa et al., 2020). Moreover, screening unnecessary genomic regions increases the possibility of reidentifying anonymised genotype data (Erlich et al., 2018). Therefore, it is imperative that only variants with explicit relevance to the chosen sporting trait (which are still yet to be determined) are included in a genetic panel. Other important issues also include how genetic data is stored and shared. Table 1 is a guide that outlines the authors' recommendations for practitioners on best practices with regards to genetic testing in sport.

Table 1
Genetic testing best practice guidelines for practitioners in sport.

Autonomy	• Athletes must be informed that they have complete autonomy around participation in genetic testing, with no negative consequences for non-participation. • Athletes must be informed that they can withdraw consent at any time and without having to provide a reason. • Should athletes want to withdraw consent, all data (including DNA samples) must be appropriately destroyed, and the athlete information must be censored from future analysis (right to be forgotten).
Discrimination	• Athletes' genetic data must not be used for talent de-selection or any other discriminatory purposes (e.g., contract length and employment particulars). Not only is this unethical, but it could open the organisation up to litigation (depending on the rules and regulations from a legal standpoint in the organisation's country).
Anonymity	• Athletes must have at least pseudo-anonymity from external bodies. • Each athlete should be issued an ID number (pseudonymity) and only the relevant organisation should have a tracking sheet identifying ID numbers and athlete names. • The minimum number of relevant individual(s) possible within the organisation should have access to this tracking sheet.
Data Storage	• The relevant organisation of the athlete is responsible for the storage of the de-identified genetic data. • The tracking sheet linking names to ID numbers should be stored electronically (no paper versions) on a separate password protected, encrypted external drive, or a personnel restricted area of a server drive.
Data Sharing	• Genetic data should never be shared using standard email servers. • Genetic data should only be shared using encrypted email servers (e.g., Virtru, Mail Express).
Data Ownership	• Genetic data is fully owned by the respective athletes (and parents/guardians if athletes are minors). • The athlete should be able to request their genetic data at any point and must be provided all data in full.
Consent	• Consent forms must be provided to all athletes (and parents/guardians if athletes are minors), which should be completed in person. • All athletes should have a cooling off period (> 7 days), whereby they have the appropriate time to consider, discuss, and decide if they would like to participate in genetic testing or not. • Consent forms must be signed and returned to the organisation before collection of genetic data commences.
Transparency	• Athletes should be fully informed on how their genetic data is being used. • Athletes should be made aware which companies and organisations have access to their genetic data.

Counselling	• Genetic data at the individual level should not be discussed with athletes. • Athletes should be explicitly recommended to organise a consultation with a genetic counsellor (i.e., an individual that can demonstrate an understanding of the area).
Education	• Practitioners should actively seek to enhance their knowledge of the latest developments and evidence pertaining to sports genomics. • Implementing an educational workshop in sports genomics may minimise the risk of all stakeholders within an organisation from misunderstanding the utility of genetic information. • This educational workshop should also be provided to athletes before they decide whether to take part in genetic testing.
Minimum Necessary Principle	• Only genetic markers fully relevant to specific sporting traits should be explored. • Only health professionals should investigate disease related genetic markers.
Data Breach Notification	• If a data breach occurs, all athletes should be notified immediately. • Athletes should be provided with details of the breach, any potential harm and/or risks, and potential next steps.

Conclusion

The current scientific evidence base does not support the implementation of genetic tests to enhance the processes of talent identification and development systems. However, as stakeholders are likely to continue using genetic tests, this paper aimed to provide practitioners with some best practice guidelines if implementing genetic testing within their organisations. Of immediate importance is the inhibition of genetic testing for de-selection/exclusion purposes. Implementing genetic testing to promote talent inclusion may help alleviate some of the systemic unconscious selection biases that exist in youth sport. Moving forward, practitioners are encouraged to increase their genetic literacy and adhere to the suggested best practice guidelines if implementing genetic testing within their organisations.

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Data availability statement

All relevant data are within the paper.