

Selection – the early prediction of future performance

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Abstract. The concept of sports medical selection has been overlooked in the literature of the past years. The medical aspects of sports selection and athletic development are essential to the fulfilment of a young athlete's potential. In this narrative review, we present the most relevant aspects of sport medical selection, aiming to introduce the six most important criteria involved in the process: medical, genetic, anthropometric, functional, biochemical and psychological. Although more research is needed, the demand for a multidisciplinary approach is evident. Monitoring the development of athletes throughout this complex process allows not only for the selection of the most apt individual, but also for the fulfilment of the potential of any young athlete, regardless of their ultimate achievements.

Key words: *sports medical selection, sports performance, athletic development.*

Introduction

Sports medicine selection is a continuous process, based on scientific criteria, which early detect and subsequently validate the talented athletes. In the world of sports, the search for talent has been an area of interest for several decades, for the benefit of athletic performance and sports ethics. Many programs have been developed in order to track down talented subjects who have an adequate biological potential. As exciting as they might appear, these programs have often failed to meet expectations, with previous performance being oftentimes misinterpreted as talent (1). Moreover, some authors, as well as the general public, have raised concerns regarding the impact of talent identification and development programs on young athletes' health (2).

As sports and exercise physicians, we should always strive to preserve and improve the health of athletes, and talent identification and development processes are no exception to this rule. The literature regarding the medical aspects of sport selection is scarce and the need for an interdisciplinary, holistic approach in sport selection is dire. Current programs aiming to identify and develop the potential young athletes have often failed to meet expectations; moreover, it seems that these programs can have a detrimental effect on the health of young athletes (1). The aim of this narrative review is to present the current knowledge regarding sports selection and orientation, focusing on the medical aspects involved in the two processes.

Sports medical selection and the medical criterion

Sports medical selection is a complex system operating with objective variables, applied to children and young adults, which aims to detect the complex potential that, under the influence of scientifically based training would lead to great performance, without hindering growth, academic development or health (Fig.1)(3). This definition highlights the importance of continuous monitoring during the selection process, in order to assess the effects of training on the gifted individual, as well as detect the potentially detrimental effects promptly.

The sports selection process is a dynamic one, which is divided into steps adapted to each stage of an athlete's professional development. The first stage is termed "initial selection" (primary selection), and it involves identifying promising individuals of a certain age, depending on the sport, and beginning the development process, i.e. using evidence based training methods in order to help the subjects fulfil their potential in a certain sport or sports discipline. This stage is followed by secondary selection, a process occurring after a minimum of four years of training, following the primary selection process.

This step involves a re-evaluation of the athlete, from a medical, psychological, social and athletic point of view. As a result of this re-evaluation, the athlete may be deemed fit to continue training in the same sporting

discipline or follow the reorientation process, which can involve switching the playing position (in team sports) or changing the sporting discipline entirely (for instance, a speed-skater may fare better in a hockey team). The final stage is termed “final selection”, and it has the purpose of selecting elite level athletes for the most important competition of the sport/sporting discipline – usually the Olympic Games or the World Championships. The sports and exercise physician must oversee this process and verify the athletes’ health status at all stages.

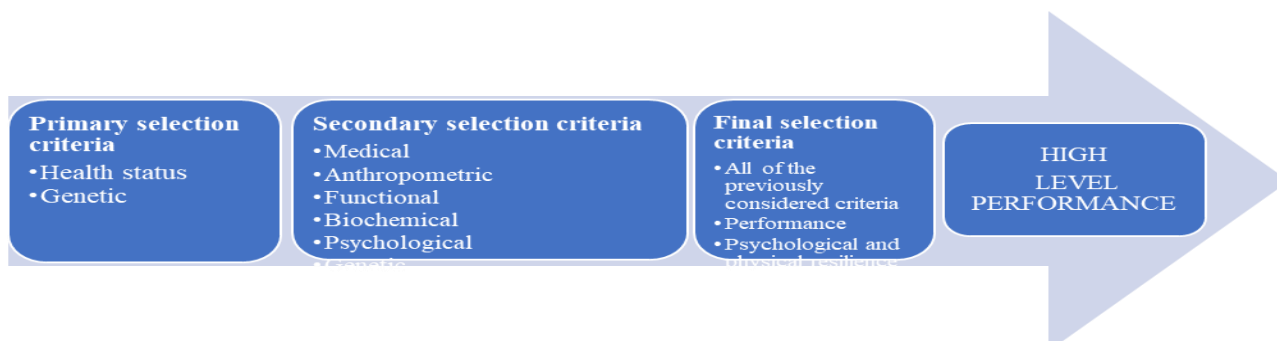


Figure 1. The stages of sports selection and the most important criteria involved in decision-making

The primary selection stage involves observing subjects of a certain age group and acquainting them to a certain sport or sporting discipline. The ideal age group for the primary selection varies and it is tailored to the sport or sporting discipline for which selection is being undertaken. For instance, for gymnastics, the target group would include children aged 5-7 years, while in boxing 10-13 year olds would be considered (4). The age of primary selection is the age at which training with the prospect of achieving high performance in a particular sport can be initiated.

Initially, individuals are chosen through direct observation by scouts, recruiters, coaches and sport scientists or through formal talent identification programmes. Talent identification (TI) is defined as “the process of recognizing current participants with the potential to excel in a particular sport”, while talent development (TD) refers to “providing the most appropriate learning environment to realize this potential” (5). Talent identification is a challenging, multi-disciplinary effort, with currently little conclusive research to support decision making (1). The scientific literature available focuses primarily on male participants [(1, 6) and most available studies have a cross-sectional design; furthermore, the accuracy of the models proposed so far has been poor (1, 6, 7). Nevertheless, there are exciting prospects and the data provided through research of the shortcomings of talent identification programs so far brought to light some concepts worth considering. Baker et al (2018) presented the factors pertaining to talent identification and development and placed them into 5 distinct categories: 1) training and experience related factors, 2) ability/skill domains (biological, psychological, cognitive/perceptual, motor/technical), 3) relative importance of each characteristic when it comes to adult-level performance, 4) the environmental malleability of each characteristic and 5) circumstantial factors (such as age compared to peers, family socio-economic status and characteristics of early developmental environments) (7).

From a medical perspective, the initial selection must identify and select only those subjects with an optimal health status, from the pool of talented individuals. This requires careful examination of the individual and ruling out any health conditions which would increase mortality or pose an increased risk of injury during sports participation. Family history is of exceptional importance at this stage, and must be carefully assessed. Any health issue identified, whether it is of a congenital or acquired nature, must be addressed before the selection process can continue. It is recommended to pause the selection process for the afflicted individuals and formulate adequate exercise recommendations in order to help them overcome their ailment.

That is not to say these individuals cannot achieve athletic performance in spite of their conditions, but their health, and not performance, should be the main focus of the physician.

The medical examinations required in the initial selection stage are similar to the ones performed during a comprehensive pre-participation examination (PPE). The interpretation of the results will differ from a regular PPE however, as the main goal is not only to determine the aptitude of young athletes to participate, but rather to detect any health issue which might pose a threat to achieving high athletic performance, even if

it would otherwise permit participation in sporting activities. To this end, several examinations are suggested, including a thorough personal and family history, physical examination, specific diagnostic tests to rule out pathology of cardiovascular, pulmonary, orthopaedic as well as neurologic and psychiatric nature, as well as provide information to determine the evolution of the young athlete throughout the selection process (3). The result of the primary selection stage is to introduce young individuals to the sporting discipline best suited to their characteristics.

The secondary stage of selection aims to assess the development of a promising individual after a minimum of 4 years of training, following primary selection. Most individuals undergoing secondary selection will be 12-16 years old. At this point, the goal is to determine whether or not an individual's characteristics are in line with the somatotype corresponding to the target sport (the achievement of the biological micro-model of the performer). To this end, all selection criteria will be relevant, and achieved performance will be analysed. This can be a turning point for many athletes, as they may not be deemed adequate to continue training in the same sporting discipline, which is when sports orientation can help reorient the individual.

Sports orientation is the process of directed sports requalification, based on the particularities of an individual. Athletes must be continuously monitored from a medical and psychological perspective; if athletes seem to develop skills which may be better suited for another sporting discipline, or if they report low levels of satisfaction in their current sport, it is advisable to consider orientation towards another sport. For instance, a young speed skater achieving average performances could be oriented towards another sport, such as ice hockey (3).

The final stage of sports medical selection – sometimes termed the Olympic selection (3). – is the stage at which high level athletes undergo a final selection process, based mainly on the achieved performances. At this point, most athletes will have achieved the biological model of the performer – that is, the biological, psychological and athletic requirements for the sport in question - and are now evaluated for competition-related variables: resilience to jet-lag, medium altitude, the psychological stress of high-level competitions, long training periods. The health criterion is of utmost importance at this stage: it is advisable to choose the athletes who display the best health status, physical and psychological resilience.

At all levels of the selection process, the health criterion is one of the most important. There is no compelling evidence regarding the frequency of medical examinations in a sports selection setting; it is therefore expected that the usual evaluations will be taking place at the time of the PPE. Nonetheless, medical assistance should be sought, if necessary, at any stage of the development process.

The role of genetics and the promise of genomic markers

Although it is widely accepted that exceptional performance is attributed to a complex interaction of several factors, it seems that in the nature vs. nurture debate, nature may have a slight dominance (8). Twin studies have noted a high heritability of traits relevant to athletic performance, such as maximal aerobic capacity, maximal anaerobic power, muscle cross-sectional area and body dimensions, muscle fibre distribution, cortical inhibition, cortical facilitation, motor control and motor learning, motor cortex plasticity, neuromuscular coordination (8). Several genes and genetic variants have been studied in relationship to athletic performance, with one review indicating 120 genetic markers associated with the elite-athlete status (77 of which related to endurance, and 43 related to power/strength); nonetheless, most of the data originates from case-control and association studies which have yet to be replicated in independent samples (9). Some of the most extensively studied variants include the angiotensin-1-converting enzyme insertion/deletion (ACE I/D) and the α -actinin-3 (ACTN3) R577X polymorphisms, which have been consistently related to improved speed and a higher proportion of fast-twitch muscle fibres (8, 9). It is important to note the role of the interaction between the environment and genetic expression, a relationship which could be defined through a better understanding of epigenetics. More research is needed in order to determine the role of epigenomic alterations in the metabolic, physiological, cognitive, emotional and behavioural adaptation of elite athletes (8).

Exciting developments in the field of genetics are underway, with the Athlome Project Consortium researching genetic variants associated with elite performance, injury predisposition and training response (10). The results could dramatically transform the sport selection process, and indeed the entire field of sports medicine.

Lastly, genetic testing has known a tremendous development in the last decade, generating a great interest of the public. Unfortunately, this has given rise to an emerging market of direct-to-consumer marketing testing kits claiming to identify an individual's athletic talent, despite no scientific evidence support these claims

(11). So far, no such test has proven to be reliable, and thus should not be used or recommended in the sports selection process (11).

Genetic sex determination (GSD) has been the subject of controversy for many years now. It is a sensitive subject for the individuals involved, and it raises some important questions: should athletes with disorders of sexual differentiation be banned from competitions? Is it fair to accept genetically advantageous traits, but not the ones related to sexual ambiguity (12)? In any case, the debate surrounding this topic is far from being resolved. While GSD used to be considered commonplace as part of the initial selection (3), which is reasonable from a practical point of view, since sporting events usually divide female from male participants, the diagnosis of a disorder of sex differentiation brings a set of challenges regarding care, development and disclosure for the parents and caregivers of the prospective athlete (13). On the other hand, selecting an individual with a sex differentiation disorder, forcing them to train for many years for a sports event for which they may ultimately not be eligible would be a selection error. Currently, no research is available to support genetic sex determination in young athletes; more evidence regarding this issue would be helpful in guiding sports and exercise physician to this end.

Anthropometric measures. The ever-developing anthropometric criterion.

Various anthropometric measurements should be taken at each medical visit during the selection process, in order to monitor the young athlete's growth process and body composition. These measurements are relevant to determine the biological maturity status of the young athlete as well as provide terms of comparison to the biologic model of the performer (the ideal body measurements adapted to a sport or sporting discipline). In order to obtain a comprehensive anthropometric profile, the International Society for the Advancement of Kinanthropometry recommends several measurements, summarized in Table I.

Table I. Measurements of the full anthropometric profile, as recommended by the ISAK [26]

Basic measurements	Body mass, Height, Sitting height, Arm span
Skinfold sites	Triceps, Subscapular, Biceps, Iliac crest, Supraspinale, Abdominal, Front thigh, Medial calf
Girths	Head, Neck, Arm (relaxed, flexed), Forearm (maximum), Wrist (distal styloid), Chest (mesosternale), Waist (minimum), Gluteal, Thigh (proximal, medial), Calf (maximum), Ankle (minimum)
Lengths	Acromiale-Radiale, Radiale-Styloid, Mid-styloid-dactylion, Iliospinale height, Trochanterion height, Trochanterion-tibiale-laterale, Tibiale laterale height, Tibiale mediale – sphyrion tibiale
Breadths	Biacromial, A-P abdominal depth, Biiliocrystal, Foot length, Transverse chest, A-P chest depth, Humerus, Bi-styloid, Femur

These measurements are relevant in sports selection for two main reasons: they allow for the assessment of the developing athlete at each stage of the development process, providing relevant insights into interindividual and intraindividual variation and adaptation (14), and the collective data can show epidemiologic trends in the anthropologic evolution of the performer of each sporting discipline. We should consider, for example, the evolution of height in the general population: in most countries, the average height has increased, when comparing the data from the 19th with the data from the 20th century (15), we can therefore expect the average height data in adult athletes to increase over the years as well. Some retrospective studies have found such increases (16), with one study describing an increase of 4,3% in the mean height of rugby union players between 1955-2015; more striking, however, was the increase in mean body mass of players: 24,3% (17). The development of these variables is strongly related to the field position (17), which must always be considered when evaluating a young athlete playing team sports. Recording the anthropometric data of elite athletes and analysing it to determine the trends is useful for the accurate ascertainment of the development of the ideal performer for each sporting discipline, and provide guidance in sports selection.

The assessment of physical development is a matter of great interest when discussing sports selection. It is also one of the reasons anthropometric measurements are so relevant, as they allow for assessing the development of the young athlete and for prompt detection of any irregularities. An important aid in this endeavour is also the qualitative evaluation of the athlete, using somatoscopy and observational gait analysis. It is important to recognize developmental flaws and explore the possible causes, as well as adapt the training methodology to the findings.

The relative age effect (RAE) is a selection peculiarity in sports, with the majority of selected athletes being born early in the selection season (18). This phenomenon has been observed across all sports, although it is more prevalent in team sports. At younger ages, the differences between the athlete born early in the season compared to his peers born late in the season can be significant, due to the relative advantage, as the high rate of children's physical development will consequently improve performance. These differences are not observed in adult athletes (18). It is worth noting that many young athletes abandon competitive sports after failing to be selected, and relative age effect can be a significant determinant in this decision (18). We should therefore consider this phenomenon, especially in the setting of early talent selection, in order to make the best decision for the young athletes involved.

The biochemical criterion

Biomarkers are a topic of great interest in the field of sports medicine, with many promising candidates being studied for their role in performance. Consequently, these markers should be considered when discussing sports selection. Several biomarkers have been proposed for the assessment of nutrition and hydration status, inflammation, muscle status, cardiovascular endurance and injury risk. It is expected that more biomarkers will be validated in the near future (19).

When considering the role of biomarkers in sports selection, it is essential to note that although many have been validated for monitoring different domains of the physiology of the elite athlete, the reference ranges are usually appropriate for the general population. Moreover, single assessments offer insufficient information, therefore tracking biomarkers seems a more sensible choice, as it allows for the estimation of resting levels, as well as the natural range of fluctuation (19). Because these tests are quantitative, it is necessary to determine cut-off points, as well as assess the interindividual and intraindividual variations, for example through a Bayesian model (14). Table II summarizes the most relevant biomarkers worth considering in the context of sports medical selection (19).

Table II. Biomarkers of cardiovascular endurance and muscle status*

Domain	Biomarkers	Modification	Potential significance
Cardiovascular endurance	Iron status: ✓ Serum iron ✓ Total iron binding capacity (TIBC) ✓ Transferrin saturation ✓ Ferritin ✓ Soluble transferrin receptor ✓ Hepcidine peptide assay	↓ ↓	Reduced energy efficiency Reduced time trial performance Impaired VO ₂ peak/VO ₂ max Lower time to exhaustion
	Haemoglobin		
Muscle status • Endocrine biomarkers must be monitored for chronic changes (testing every 4-6 weeks under similar conditions) (19)	Cortisol	↑	Reduced protein synthesis capacity Impaired recovery capacity
	Testosterone	↓	Excessive training volume and/or intensity Diminished anabolic potential
	Testosterone/Cortisol ratio	↓	Suppressed protein synthesis Overreaching
	Dehydroepiandrosterone	↓	Susceptibility to overtraining
	Growth hormone	↓	Impaired potential to adapt
	Muscle damage: • Creatine kinase • Myoglobin • Blood urea nitrogen	↑	Muscle damage Catabolic state
	Amino acids • Glutamine • Glutamine/glutamate ratio	↓	Fatigue Impaired potential to adapt to training Catabolic state

*Source: Biomarkers in Sports and Exercise: Tracking Health, Performance, and Recovery in Athletes. *The Journal of Strength & Conditioning Research*; 31(10):2920-2937, October 2017[19].

Different biological products can be tested when evaluating biomarkers, the venous blood being the most common and thoroughly studied. Blood profiling is the analysis of a blood sample beyond the purpose of a medical diagnostic or anti-doping purpose, whereas blood monitoring defines frequent blood testing of an athlete, in order to assess recovery (20).

The drawbacks to using venous blood are the invasiveness of the procedure and the detrimental effects of losing blood volume for the athlete, especially for female athletes, who are prone to iron deficiency anaemia due to menstrual blood loss; these disadvantages have determined practitioners to look for alternative technologies to help monitor the biochemical profile of the athlete. New wearable technologies aim to use different biological products, such as eccrine and apocrine sweat, tears and saliva for the evaluation of biomarkers (21). These new technologies also offer the exciting prospect of real time, continuous monitoring of several components of the biochemical profile of the athlete (21).

The role of biomarkers in sports selection is two-fold: not only do they indicate the degree of adaptation of an organism to specific training, but they also offer some insights into the habits and lifestyle of an individual. If we consider the latter, it is advisable to interpret biomarkers of nutrition status (macronutrient and micronutrient metabolism) in the context of the specific diet and type of training followed by the athlete and correlate clinically. If appropriate, nutrient deficiencies should always be corrected, although this may not always result in improved performance.

Functional and effort capacity criteria

Throughout the selection process, it is advisable to perform a series of tests, according to the age and level of specialization of the athlete, in order to assess the physiological adaptations to training. In the initial sports selection stages, these tests are used to monitor the development of the athlete from a functional point of view, whereas in final selection, their main role is to determine the level of overall fitness and athletic skills achieved, and help guide the selection decision-making process. While physical tests are not recommended for the initial selection stage or for detecting athletic potential in children, as these offer no practical information regarding a child's ability for athletic development, they can be used in the development stages (between selection stages) in order to detect possible limitations and provide feedback regarding the current training protocol; the goal is to tailor the training program to the developing athlete's individual needs, to allow for the fulfilment of his potential (22).

Keeping in mind developmental stages, Lloyd et al (2012) proposed a model for the development of young male and female athletes, taking into consideration the age, growth rate, maturational status, type of training adaptation, physical qualities (and classifying them according to their relative importance throughout development) as well as the training structure (23). This model displays the predominant importance of fundamental movement skills in the earliest stages of development, with the increasing value of sports specific skills, mobility, agility, speed, power, hypertrophy, endurance and metabolic conditioning as the development process unfolds; strength remains an important physical quality throughout this process (23).

Keeping this model in mind, we should test athletes accordingly, considering the importance of each of the physical qualities relevant to their respective sport or event. This model highlights the relative importance of endurance and metabolic conditioning towards adulthood it is therefore advisable to proceed with cardiopulmonary exercise testing at this stage.

The role of exercise testing is significant for the continuous development of the athlete, and for the final selection stage, helping practitioners select only the most apt athletes for a high-level competition. While aerobic and anaerobic capacity indicators are, to a degree, genetically conditioned (3), their development depends on a customized training process.

Cardiopulmonary exercise testing (CPET) can be used to determine variables including VO_2max , $\text{VO}_{2\text{peak}}$, ventilatory aerobic and anaerobic thresholds, oxygen pulse, ventilatory reserve, ventilatory equivalents, dead space ventilation, alveolar-arterial tension oxygen difference; these allow for the interpretation of the test, as well as the formulation of personalized recommendations with the scope of performance augmentation (24). Anaerobic effort capacity can be assessed using a Wingate type protocol, in order to determine variables such as peak power, relative peak power, anaerobic capacity and anaerobic fatigue.

Choosing the right protocol and type of exercise test depends on the athlete, the sport or event – according to the metabolic demands, the aim of the test (monitoring/selection); although the Bruce protocol is the most commonly used CPET protocol, choosing an adapted protocol for each sport would yield more informative results (24).

The psychological aspects of sport selection

Recent developments have founded the role of sports and performance psychology in the selection and development of elite athletes.

Each stage of sports medical selection is aided by psychological testing, evaluating variables such as reaction time, visual-motor coordination, attention, resistance to stress and monotony and motivation, to name a few.

But the involvement of psychology goes beyond testing: continuous psychological monitoring and support offered throughout the development process of elite athletes has become an essential part of high-performance sports.

An interesting development in psychology is viewing talent as a dynamic concept, with early expression in some, but not all promising individuals (25). This perspective recognizes that some variables that contribute to extraordinary achievements may be undifferentiated at the age of selection, which must be considered when excluding young athletes from high performance sports selection. Additionally, this concept could also explain why some athletes never realize their potential, despite displaying remarkable abilities at an early age (25). This calls for a close monitoring of young athletes throughout the selection process and identifying their ability to adapt and fulfil their potential; in practice, this involves identifying psychological behaviours which either facilitate or inhibit the interaction of the individual (in this case, the athlete) with the environment (in this case, the target sport or sporting discipline).

The model proposed by Abbott and Collins (2004) for determinants of performance throughout athletic development emphasizes the importance of transferable skills (motor, perceptual, conceptual and physical) alongside psycho-behavioural elements (such as goal-setting, realistic performance evaluation, imagery skills, self-talk) in the primary selection stage, with sports-specific skills (of motor, perceptual, conceptual and physical nature) being less relevant initially. The latter becomes the most important component towards the late stages of athletic development, with psycho-behaviours becoming the second most important determinant of performance (25). This model also recognized four stages of an athlete's development, each being separated by a macro-transition: the sampling stage, the specializing stage, the investment stage and the maintenance stage; psycho-behaviours (goal-setting, self-reinforcement, planning and organization, effective and controllable imagery), psychomotor (hand-eye coordination, balance) and physical factors all contribute to the transition between these stages. Including the maintenance stage (the stage after the fulfilment of one's potential, where the main objective is consistent performance) in this model is an important reminder of the need for psychological support throughout one's athletic career; this model also recognizes the importance of sports orientation, noting that developing athletes should be guided towards an alternative sport if their performance dispositions should prove more appropriate for that certain sport (25).

An issue worth considering when it comes to sports selection is the effects of early specialization on young athletes. While it is acknowledged that in some sports (such as gymnastics, figure skating or diving) early specialization is required in order to achieve high performance, due to the early achievements of peak-performance, concerns have been raised regarding the associated psycho-social risks of training intensively in a single sport, with injury, overtraining and burnout being the most common adverse outcomes (1).

It seems that engaging in several different sports throughout childhood and early adolescence is associated with improved skill development, greater satisfaction and a lower risk of injury. Although more research is needed in order to determine the role of late-specialization in achieving high performance and in guiding sports selection accordingly, it is clear that the vulnerabilities athletes are prone to during early specialization must be identified and managed promptly. It is also worth looking into the external factors which contribute to the decision to specialize early: the influence of coaches, relatives, but also the limiting factors – costs, location, opportunities to participate in different sports (1).

Conclusions

The medical aspects of sports selection have often been overlooked, leaving athletes vulnerable to a series of adverse effects related to improper athletic development management. The need for a multidisciplinary approach to sports selection has become obvious, as the achievement of extraordinary performance is a complex system, requiring careful monitoring and customization.

Athletes must be monitored and guided throughout their development; this does not only improve their performance, but also shields them from the adverse effects of intensive training during childhood and adolescence; sports orientation is an important part of the selection process for those who seem to not meet their potential in a certain sport, and may fare better in a different sport.

More research is needed in order to determine the factors involved in achieving outstanding performance and how these can be influenced through external interventions, as well as establish evidence-based guidance on decision making throughout the sport medical selection complex.

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