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Determinant of Heredity Related Trainability

by

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Authors summarized chosen data about genetic endowment of motor abilities and its trainability according to different methods of establishing heritability. Collected data on genealogy of some prominent "Olimpic Families" and on genetic determination of fundamental predispositions to several branches of sport activities enabled to form some important conclusions directed to coaches and high-performance athletes.
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Introduction

One of the disputable items of high-performance sport relates to the relationship between genetic and training related factors of sports success. It is obvious that Olympic champions and other outstanding athletes are not usual people. Definitely, their extraordinary abilities are associated with exclusive sport talent, which is unquestionably partly determined genetically (review Bouchard et al. 1997). Certainly, talent as the notion includes many ingredients; one of them is, that outstanding athletes respond to training loads better than "usual" people. This feature (positive reaction to training) is called *trainability*. Trainability can be characterized as an ability to improve the motor potential of athlete by means of training stimuli, with respect to age, sex and structure of training loads.

In order to understand the nature of sport talent, the possibilities and limitations of athletic training, the following questions should be answered:

1. Does heredity contribute to sport success?
2. What is the genetic endowment of main somatic and functional traits?
3. To what extent the response to training stimuli (cumulative training effect) is genetically dependent?

All of the above questions belong to the area of sports genetics. Heredity contribution to physical activity and athletic performance has been extensively studied. Specific approaches of genetic investigations, which can be applied to sport, include twin studies, family investigations and experimental studies on trainability.

The purpose of this review is to summarize and simplify the available data related to influence of heredity on athletes trainability from the point of view of high-performance sport.

Results and discussion

1. Outstanding sport families.

Family studies are not frequently used in genetic investigations: somatic and physiological traits of parents and their offspring were evaluated (review Szopa 1986, Malina and Bouchard 1986, Bouchard et al. 1997) in different populations of Europe and North – America: their results displayed great differentiation, both in respect to type of relation and to population under study.

Unfortunately, classic quantitative genetic methods have a lot of limitations, especially in case of analysis the outstanding sport families. Coaches and sport

scientists noted however, that parents of top-athletes are usually (both physically and functionally) to a higher degree developed, than the whole population and often experienced in high-performance sport. Some of them achieved outstanding results. Table 1 presents some of the so called “sport dynasties”.

Table 1. Examples of the families of world, Olympic champions and medal winners (Sources – Kamper, 1983; Shvarts, Khrushchov,1984, Guinness book-Matthews P., 1997).

Parents, country	Sport, achievements	Children, country	Sport, achievements
Father - Casmir Gustav, Germany	Fencing. Two gold and two silver Olympic medals at 1906	Son – Casmir Erwin, Germany	Fencing. Two silver Olympic medals at 1928; two bronze Olympic medals at 1936
Father - Swahn Oskar Gomer, Sweden	Shutting. Olympic champion at 1908, 1912; Olympic silver medal at 1920	Son – Swahn Alfred., Sweden	Shutting. Olympic champion at 1908, 1912; Olympic silver medals at 1920 and 1924
Father - Gerevich Aladar, Hungary	Fencing. Olympic champion at 1932, 1936, 1948, 1952, 1956 and 1960	Son – Gerevich Pal, Hungary	Fencing. Olympics bronze medal at 1972
Mother – Szekeli Eva, Hungary	Swimming. Olympic champion 1952; silver Olympic medal at 1956	Daughter – Gyarmati Andrea,	Swimming. Silver and bronze Olympic medals at 1972,
Father - Gyarmati Dezso, Hungary	Water polo. Olympic champion 1952, 1956, and 1964; silver Olympic medal at 1948; bronze Olympic medal at 1960	Hungary	European champion and two silver medals at 1970
Father - Tishtenko Anatoli, USSR	Kayaking. World champion at 1970, European Champion at 1971	Son - Tishtenko Anatoli, USSR, Russia	Kayaking. World champion in kayak-double and four at 1990, 1993, 1994 (200, 500 and 1000m) and 1995
Father - Hall Gary, USA	Swimming. Silver medal at Olympics 1968 and 1972, bronze medal at Olympics 1976	Son - Hall Gary, USA	Swimming. Two Gold medals (relays) and two silver medals at Olympics 1996: Olympic champion 2000 (1 individual event, twice – relay)

Parents, country	Sport, achievements	Children, country	Sport, achievements
Father - Anissin Viacheslav, USSR	Ice hockey, European and World Champion at 1973, 1974, and 1975	Daughter – Anissina Marina, France	Figure skating. Olympic champion 2002; Olympic bronze medal at 1998; World champion 2000; silver medals 1998, 1999 and 2001; European champion at 2000 and 2002
Father - Bure Vladimir, USSR	Swimming. Silver and two bronze Olympic medals at 1972, bronze Olympic medal at 1968, European champion 1970	Son – Bure Pavel, Russia, USA	Ice hockey. Olympic silver medal at 1998; Olympic bronze medal at 2002; Awards: Maurice Richard –goals leader (2), NHL All-star team (6)
		Son – Bure Valery, Russia, USA	Ice hockey. Olympic silver medal at 1998; Olympic bronze medal at 2002; NHL All-star team (1)

Certainly, each outstanding athlete (Olympic, world champion and medal winner) is unique. Occasional occurrence of two outstanding athletes in subsequent generations of one family is negligible; each sample of such family can be analyzed as a case study. The investigation of these cases is of great interest for understanding the nature of sport talent and importance of heredity related factors.

Very often the children of great athletes were oriented from early childhood. It is than possible that their training conditions were more favorable than these of the average population. This factor's influence can not be ignored. However, outstanding parents had to be genetically predisposed to certain sport activities. This heredity related benefits were partly transmitted to the offspring. Hence, probability to succeed in high-performance sport is much higher in children of champions. According to Sergijenko (2000), the offspring of outstanding athlete has 50% probability to inherit excellent athletic abilities. This probability reaches 75% in the offspring of parents consisting of two outstanding athletes (the last case occurred once in our list – family of Andrea Gyarmati).

2. Genetic determination of somatic and physiological traits.

Quantitative estimation of inheritance allows to consider the first question and to answer the second one.

The most widely used method to assess heritability of several traits is the twin investigation. In general, the idea of twin method based on the comparison of the resemblance of monozygotic to dizygotic twins. This method has very serious limitations (review Szopa 1986, Malina and Bouchard 1986, Bouchard et al. 1996), which caused, that only a few can be treated as methodologically correct. More valuable – in our opinion – is the family method (phenotype resemblances), but it was used only occasionally. In our considerations data both from twin and family studies is considered.

A somatotype understood as compilation of body linear, broad and fatness dimensions is under different genetic control: linearity – strong, breadths and muscle mass – medium, fat mass – weak. Their meaning as indicators of sport predispositions is different. Body height is an important predisposition to many sports. Body breadths can be also important as a factor affecting suitability for certain disciplines, despite of small heritability. Total body fat is to a small degree controlled genetically. Hence, the athlete's body can be significantly changed through training and diet (excluding linear dimensions). One must remember that heritability indices vary from population to population and are dependent on environmental variance and precision of methodology used by particular investigators (Szopa 1986, 1990, Szopa et al. 1999, Bouchard et al. 1997). Higher values of heritability indices are typical for twin method, because it presents "heritability in a broad sense" (total genetic variance). Family studies leads to determine heritability "in a narrow sense" (only additive variance). These facts cause that the only possible and correct way of interpretation of h^2 is relative treatment of this coefficient in generalized categories: high – medium – low genetic control. This kind of attempt is presented in Table 2.

Table 2. Approaching heritability of main somatic traits (based on Kovar 1980, Shvarts and Khrushtchov 1984, Szopa et al. 1985, Szopa 1990, Bouchard et al. 1997,)

Characteristic	General genetic control	Approaching mean value of h^2
Body's lengths: height, extremities, foot	strong	70%
Body's breadths: shoulders, thigh etc.	medium	50%
Total body fat	low	20 – 30%

Muscle mass	medium	40%

The most important somatic property (almost totally controlled genetically), strongly determining individual predispositions to speed or endurance – related disciplines is the ration of FT/ST muscle fibers. It does not change during individual life and is not susceptible to training: that is why this variable should be taken into account during first stages of sport selection.

Similar studies have been conducted with regards to heritability of several motor abilities (Table 3).

Table 3. Heritability of several motor abilities characteristics (based on Kovar 1980; Mleczko 1992, Szopa et al. 1996, Klissouras 1997; Bouchard et al. 1997)

Characteristics	General genetic control	Approaching mean value of h^2
Alactic Anaerobic Power	strong	70-80%
Lactic Anaerobic Power	medium	~ 50%
Peak blood lactate	high	~ 70%
Aerobic Capacity (V_{O2} max)	low-medium	~ 30%
Maximal isometric strength	low (mainly by mother genotype)	20-30%
Strength endurance (resistance to acidity)	medium	40-50%
Reaction time	low	20-30%
Coordination of arm movement	medium	~ 40%
Space orientation	high	~ 60%
Balance	medium	~ 40%
Frequency of movements	medium	40-50%
Flexibility	medium	~ 40%

This table includes only main functional abilities, but most important in many sport disciplines. As we can see, they are in general under much less (than somatic traits) genetic control. The main reason of this phenomenon is great *ecosensitivity* of enzymatic background of physiological processes and simple coordinative properties. These traits are than more trainable than majority of somatic ones. It is worthy to emphasize, that in older papers estimated values of h^2 were much higher than in new, methodologically more correct investigations.

The mostly relevant metabolic characteristic was maximum aerobic capacity (oxygen uptake). Its history can serve as a perfect example of the evolution of views of particular investigators: from very high estimation of heritability of this ability in former works (over 90%) to relatively low and trainable (h^2 about 30%) in new publications (review see Bouchard et al. 1997). Additionally, there is great probability of determining this ability only by mother mitochondrial DNA. Particularly high level of genetic determination was found in regard to anaerobic (especially alactic) power and peak of blood lactate: in consequence – explosive strength, speed abilities etc. are strongly controlled genetically. High stage of genetic contribution displayed the co-ordination abilities steering by highest floor of nervous system like space orientation, intelligence etc. The rest of functional abilities demonstrated medium or low heritability and at the same time – great trainability.

In light of heritability of various somatic traits the general situation with the event – specific trainability is more understandable. We must however remember, that genetic determinants are important, but are not the only element of this phenomenon.

3. Genetic determination of cumulative training effect

It should be emphasized that athletes are individuals, who inherited ability to respond well to training stimuli. However, the extent of inheritance is very different with regards to several motor abilities. Moreover, heritability of certain motor abilities and heritability of trainability are probably independent (h^2 is a population mean value, trainability – individual trait) and can be different. Relations between heredity dependent ability and training response can be described by three following options:

- the motor ability is strongly genetically determined, the effect of training for this ability is strongly heredity dependent as well; in this case the final state of performance of an athlete are decisively genetically conditioned;
- the motor ability is strongly genetically controlled, but the effects of training for this ability is moderate or low inherited: in this case the final state of athletes performance is moderate genetically determined;
- both the motor ability and its trainability are in a low degree heredity dependent: at this case the final state of motor fitness of the athletes is to a low degree determined by heredity and other factors (preparation, restoration etc.) are of primary importance.

Additionally, other factors are of significant importance too: athletes genotype, initial level of motor abilities, age, sex etc. (Bouchard et al. 1997).

There are many studies, in which heritability of the response to training was investigated. Most of them were devoted to $V_{O2\ max}$ changes. Few studies considered long-term training directed to other abilities and their results can be considered as the cumulative training effects, but only one study was devoted to "training – detraining – retraining" including different abilities in 12-year old Polish boys (Szopa and Prus 1998). Their results (table 4) confirmed our earlier observations: the higher genetic control, the smaller the trainability and vice-versa, as well as great differences in individual response to training. Many works pointed to the relation between trainability and current phenotype (Bouchard et al. 1980 – correlation about -0,5) and volume of training.

Table 4. Cumulative training in chosen studies (after Malina and Bouchard 1986, Bouchard et al. 1997, in own modification)

Training characteristics	Effects	Authors
24 sedentary subjects, 20 weeks of aerobic training	Main improvement 33%, gains ranging from 5% to 88%, MAC 60% more then MAP	Lortie et al. 1984
10 pairs of M 2 twins, 20-week endurance training 4 to 5 trainings (40-45 min) per week	MAP improved by 14%, ranging from 0% to 41% of $V_{O2\ max}$	Bouchard 1983
14 pairs of M 2 twins, 15-week intensive training anaerobic	MAP/kg and MAC/kg improved by 22% and 17% respectively, individual differences ranging from 0 to 65%	Boulay et al. 1984
3-year "training – detraining – retraining" experiment, universal training of main motor abilities (strength, anaerobic, aerobic and co-ordination) in 120 boys aged 12-14	Great trainability in first period (training) and much greater in third period (retraining) related to training loads and structure. Greatest trainability of strength and aerobic capacity. Reverse changes in period of detraining.	Szopa and Prus, 1999

Bouchard (1984) believes, that trainability of $V_{O2\ max}$ understood as genotype times environmental effect may be estimated as 40-50% with very significant individual differentiation (5-60% in MAP/kg). According to his opinion elite athletes are well endowmed (G effect) and are high responders to training stimuli (GxE effect and related components).

What about other motor abilities, their trainability is dependent on strength of genetic control of particular ability, age, sex, initial level and age – as well as individual genotype determining ecosensitivity.

Special attention should be done according to genetic control of motor learning and technical skills perfection. Present state of investigations pointed to great differentiation between groups according to age, sex, kind of task, lasting – time of experiment etc. (Bouchard et al., 1997). Till now there are no investigations on learning processes of master – technique in top – athletes. Nevertheless the results suggest that learning of simple skills in slightly genetic dependent, but significance of this factor grows with the growing complications of movements (mentioned above relation between genetic control and "floor of steering processes").

In conclusion it should be emphasized that top-athletes are individuals, who inherited several somatic and physiological benefits as well as the ability to respond well to training. Combination of these two factors determines the possibility of reaching a high level in sport skills and can be treated as main predispositions of sports talent. However final result of sports training (technical and motor mastery) depends predominantly on his/her long – term preparation. This gives a lot of freedom for coaches' creativity, which even allows compensating (although partly) genetic limitations. On the other side, the rational interpretation of the heredity dependent traits allows to select practically acceptable exams and criteria for the gifted youngsters' identification (Lustig, 1996). In addition, life conditions should be mentioned as relevant factor supporting trainability: nutrition, sufficient rest, biological restoring, supplementation, normal conditions for professional activity, proper psychological climate and social conditions. Experiences of many athletes' generations give a lot of examples when deflection from the rational life style distorted the training effects and, in extreme cases, followed to failure of adaptation.

Final remarks

The available data allows toconclude that genetic factors are very important in high sport achievements, determining several somatic and physiological traits important in given discipline. This factor determines individual trainability, too. It means that appropriate training stimuli can indeed profoundly affect the development of the athlete's motor potential in the frames of genetic limitations. Rational training and personality traits are of equal importance in developing an Olympic athlete.

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