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Genetic Endowment of Coordination Motor Abilities a Review of Family and Twin Research

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This paper is a review of family and twin research related to genetic and environmental endowment of coordination motor abilities. Basic methodological assumptions were presented for such research, as well as the conditions that must be met in order to make the research reliable. The results indicate that only space orientation is strongly controlled genetically, while significant genetic endowment is observed in case of eye-hand coordination and speed of movement. For all other coordination abilities considered the genetic indexes were varied. It was concluded that further research is required in this field, conducted on families and twins with the application of new methods and innovative methodological considerations.

Key words: *genetic endowment, family similarities, heredity, coordination, motor abilities, twins*

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Introduction

Recently significant attention has been directed at the relationships between genetic and environmental endowment of different structures and functions of the human organism. A continuous advancement in biological sciences and statistics, allowed combining research methods applied in qualitative genetics, population genetics and biology (Osiński 2000). In genetic research of quantitative traits (polygenetic heredity), conclusions are made on the basis of variability of observed phenotypes (unmeasured genotype approach). The basis of this method were established in the early years of the 20th century in works of Fisher (1918) and Haldane (1932), and than further developed in the seventies by Mather and Jinks (1963), Falconer (1974) and Susanne (1976). Such conclusions are especially valuable in determining the phenotype variability of functional traits, which include elements related to coordination motor abilities.

On the other hand greater demands in the area of coordination are placed on athletes from different sport disciplines in order to achieve technical perfection in the future. It seems that those reserves lie in the improvement of motor coordination. Considering an equal level of conditioning, the level of motor coordination will determine future motor activity effectiveness. Thus it seems, that the higher the level of motor coordination in a youth athlete, the faster he will learn complicated techniques and tactical strategies. Such an athlete will also reach a higher sports level.

From the above considerations many practical questions for sport arise. For example, which criteria should be used as selective means for particular sport disciplines, and which are priorities? The answers must be seeked in works dedicated to sport science as well as in those related to genetic and environmental endowment of traits during the ontogenetic development. In building the championship model for a certain sport discipline, it is wise to use a group of properties that determine high effectiveness and have a strong genetic endowment, which means they are not or marginally susceptible to training stimulus.

Considering the above mentioned data, it seems, that this paper may contribute to a better understanding of the relationships between genetic and environmental endowment of chosen aspects of human motor coordination, so vital in competitive sports.

Basic methodological assumptions

As mentioned in the introduction, research on genetic endowment of different human traits has been going on continuously since the twenties of the past

century. Since that time many works have been dedicated to the methodology of genetic research (Fisher 1918, Falconer 1974, Susanne 1976, Szopa 1986, Bouchard et al. 1997, Malina et al. 2004, Żychowska 2004). In this paper only the basic assumptions of genetic research methodology will be presented. For a deeper enquiry of literature in this area, the reader should search the above mentioned references.

The most often method applied in genetic research includes the statistical analysis of the phenotype: twins, siblings or the relationships of particular traits between parents and children. As a supplementary method, which only allows to detect traits of low heredity the method of "longitudinal development stability" may be applied (Welon & Bielicki 1971, Kovař 1980, Bergman 1988, Szopa 1991). All these methods are based on the analysis of phenotype variance (V_t) of particular traits. From this model arise specific methodological assumptions, which determine the elements of variance possible for assessment with different methods (twin and family research) and the possible research material (environmental variance). According to literature review the first one seems to be decisive, because depending on the methodology, different components of variance are estimated. This was often not included in research projects. One must underline the fact that the method of family similarities allows to estimate heredity in a very narrow sense (the input of additive variance in the whole variance of a trait). The twin method is much more complete in estimating heredity (input of total genetic variance in the whole variance of a trait). The application of different research methods causes the great variability of results in estimating the heredity of certain traits. Most often, twin research, especially early findings overestimate the heredity indexes for many traits in comparison to data from family studies. The most important considerations for family research include:

Perform the calculations on normalized values what excludes generation and group differences in variance and allows for a comparison of traits.

Calculate correlation coefficients between parents in several age groups, what will allow evaluating both the influence of selective mating as well as the effect of "living together" which can be a measure of family environment. This allows for corrections in interfamily relationship indexes, which are often overestimated in cases of positive selective mating.

Perform the calculations on as many subjects as possible since this has a direct effect on random variability of correlation coefficients (Szopa 1986, Mleczko 1991). Generally, the higher the number of studied cases the greater the stability of coefficients calculated in different types of combinations in family heredity.

Literature review

Somatic variables are among the best researched elements related to genetic endowment. There are numerous cross section studies conducted on twins (Clark 1956, Orczykowska-Świątkowska 1968, Skład 1972, Orczykowska-Świątkowska & Lebioda 1975, Bergman 1976, Szczotka, Szczotkowa & Lebioda 1977, Bergman 1995), family cross section research (Malina et al. 1976, Szopa 1976, 1977, 1978, 1985, Malina 1986, Jaworski & Szopa 1998, Szopa et al. 1999, Malina et al. 2004), as well as longitudinal twin studies (Bergman 1988, Bergman 1995) and family research projects (Welon & Bielicki 1971, Szopa 1991). The above mentioned are only few of the many papers considering the genetic endowment of somatic variables. The analysis of this literature allows to state that the highest heredity in somatic variables is related to the structure of the skeleton, especially long bones, of which heredity indexes equal from 0,6 to 0,9. Width variables show lower heredity values (0,5-0,6), lean body mass LBM (0,4-0,5), while the lowest values of heredity are shown for fat tissue content, which is highly dependent on environmental factors such as diet and physical activity. From the point of methodological considerations, the knowledge of these indexes is important; since they are related to in the evaluation of genetic endowment of functional predispositions (a comparison of currently evaluated functional indexes with somatic ones with established strength of heredity). On the other hand there are view studies related to genetic endowment of functional traits. When considering research on heredity of motor abilities the least data appears on coordination motor abilities. Below is a short review of research conducted on different populations and with different methods relating to the genetic endowment of chosen coordination abilities.

Speed of simple reaction

Among heredity research conducted on motor coordination, the most abundant are those related to simple speed of reaction, determined on the basis of twins (Vandenberg 1962, Švancara 1971, Komi et al. 1973, Skład 1972, 1973, Sergijenko 1975, Kovař 1980, Cianas 1988, Rijsdijk et al. 1995, Starosta 1999, Ljach & Starosta 2001, Ljach 2002). Below are presented heredity indexes from twin studies.

Much of the family studies related to speed of simple reaction have been conducted in Poland (Wolański & Pyżuk 1973, Wolański & Kasprzak 1979, Szopa et al. 1985, Szopa & Mleczko 1987, Mleczko 1991, Jaworski & Szopa 1998, Jopkiewicz 1998, Wieczorek 2006). Results of family studies are presented below.

Table 1

Sample heredity indexes (h^2) for speed of simple reaction time obtained by the twin research method.

Author	Value of h^2
Vandenberg 1962	0,22
Švancara 1971	0,70
Komi et al. wsp. 1973	0,86-0,97
Skład 1972, 1973	0,56 – 0,77
Sergijenko 1975	0,71 – 0,86
Kovař 1980	0,70-0,86
Rijsdijk et al. 1995	0,77
Starosta 1999	0,56 – 0,86
Ljach & Starosta 2001	0,71
Ljach 2002	0,52 – 0,72

Table 2

Heredity indexes (h^2) of speed of simple reaction time evaluated on the basis of family studies.

Author	Value of h^2
Wolański & Kasprzak 1979	0,69
Szopa et al. 1985	0,21-0,31
Szopa & Mleczko 1987	0,15-0,39
Mleczko 1991	0,19-0,39
Jaworski & Szopa 1998	0,24-0,26
Jopkiewicz 1998	0,29-0,56
Wieczorek 2006	0,18-0,34

In general it can be stated, that on the basis of the above presented data, early research findings show higher heredity indexes for simple speed of reaction than more recent ones, conducted with proper methodology. Different values of heredity indexes were obtained for lower and upper limbs, for minimal and maximal reaction time, as well as for the type of stimuli (visual or auditory). It seems that the cause of such a state of research has to be pinpointed to methodological faults (sample size, not considering age and sex differences, not excluding enviromrntal factors, and determining different components of genetic variance). It can thus be concluded that the speed of simple reaction time is a coordination ability, with moderate genetic endowment.

Complex speed of reaction

The data related to the genetic endowment of complex speed of reaction is scarce. Research related to this ability has been conducted mainly on twins in Moscow (Wasilec1975, Ljach 2002). These results indicate that this ability is strongly determined by heredity, yet it is difficult to draw such conclusions upon two research projects. There are basically no family studies in relation complex speed of reaction.

Movement speed

Not many research projects have considered the influence of heredity on movement speed. This motor ability is a combination of metabolic, coordination and structural predispositions. Most often it was evaluated through hand or leg tapping. Research related to genetic endowment of movement speed has been going on continuously since 1929 (Holzinger 1929). The review of twin research in this area (Schwarz 1972, Vandenberg 1966, Kovař 1974, Skład 1973, 1975, Sergijenko 1975, Nowożiłowa 1976, Maes et al. 1993) reveals heredity coefficients in the range of 0,32 to 0,87. Such a great dispersion of results is most likely the outcome of a different number of twins considered and different research methods applied. The results indicate higher heredity indexes in male than in female twins. Also some authors (Skład 1975 and Vandenberg 1962) observed higher values of heredity indexes for the right hand in comparison to the left one. Results of heredity indexes calculated for movement speed are presented in table 3.

Table 3

Sample heredity indexes (h^2) for movement speed obtained through research with the twin method..

Author	Value of h^2
Schwarz 1972	0,87
Skład 1973	0,76-0,83
Kovař 1974	0,13-0,64
Skład 1975	0,30-0,58
Nowożiłowa 1976	0,32

Family research (Wolański & Kasprzak 1979, Kovař 1981, Sergijenko 1990, Carlier et al. 1994, Jaworski & Szopa 1998, Jopkiewicz 1998, Cieśla 2005, Wieczorek 2006) has also brought great variability of results, with heredity indexes ranging from 0,01 up to 0,72. The results of the latest family research in Poland are presented in table 4.

Table 4

Heredity indexes (h^2) for movement speed estimated through family research.

Age Group	Kielce [1] 1992 -1996			Kielce [2] 1995 -1996			Żywiec [3] 1995-1996			Kielece[4] 2001-2002		
	S	D	G	S	D	G	S	D	G	S	D	G
7-10	0,44	0,54	0,49	0,02	0,01	0,02	0,20	0,08	0,14	0,21	0,15	0,18
11-14	0,38	0,48	0,43	0,32	0,26	0,22	0,36	0,36	0,36	0,34	0,30	0,31
15-19	0,50	0,64	0,57	0,72	0,22	0,49	-	-	-	-	-	-

Legend: S – son, D - daughter, G - general

1- Jopkiewicza 1998, 2 - Cieśla 2005, 3 – Jaworski & Szopa 1998, 4 – Wieczorek- 2006

The analyses of the above presented results indicate great variability with heredity indexes ranging from 0,01 to 0,87. As a rule the values are higher for twin research. It is interesting to notice that the values of heredity indexes rise with age, what may suggest that the whole genetic potential is exposed when full development of a certain functional trait occurs (Szopa & Mleczko 1987). The same is true for other coordination abilities such as eye-hand coordination, space orientation and court intelligence.

Considering the available data it is difficult to unequivocally determine the genetic endowment of this motor ability. Having in mind the hybrid character of movement speed, one can assume a moderate genetic control of this ability.

Balance

The amount of well conducted research projects evaluating the genetic endowment of body balance is also low. The estimated heredity (h^2) indexes based on twin research range from 0,12 to 0,78 (Vandenberg 1962, 1966, Skład 1973, Williams & Hearfield 1973, Williams & Gross 1980, Sergijenko & Rybakow 1984, Ljach i Starosta 2001, Malina et al.2004), and are higher for static than dynamic balance (Malina et al. 2004). Table 5 presents data of heredity indexes from twin research related to body balance.

Results of earlier family research by Wolański & Kasprzak (1979) indicated heredity indexes of 0,11 for static balance and 0,37 for dynamic balance. More recent data from research conducted in Poland (Jaworski & Szopa 1998, Cieśla 2005, Wieczorek 2006) show heredity indexes ranging from 0,02 to 0,82.

Table 5

Sample heredity indexes (h^2) for body balance obtained through research with the twin method.

Author	Value of h^2
Vandenberg 1962	0,24-0,48
Williams & Hearfield 1973	0,46
Skład 1973	0,75-0,78
Williams & Gross 1980	0,27-0,69
Sergijenko & Rybakow 1984 (static balance)	0,31-0,74
Sergijenko & Rybakow 1984 (dynamic balance)	0,12
Ljach & Starosta 2001	0,22

Table 6

Heredity indexes (h^2) for body balance estimated through family research.

Age Group	Kielce [1] 1995 -1996			Żywiec [2] 1995-1996			Kielce [3] 2001-2002		
	S	D	G	S	D	G	S	D	G
7-10	0,06	0,28	0,17	0,36	0,82	0,59	0,31	0,02	0,23
11-14	0,64	0,10	0,37	0,60	0,24	0,42	0,06	0,08	0,08
15-19	0,78	0,60	0,69	-	-	-			

Legend: S – son, D - daughter, G - general

1 - Cieśla - 2005, 2 - Jaworski & Szopa 1998, 3 - Wieczorek 2006

Reassuming the review of results related to the genetic endowment of body balance, one can observe a significant variation of heredity indexes depending on the evaluation method, research population and age of the tested subjects. These divergences do not allow to univocally determine the genetic control of body balance.

Space orientation and eye-hand coordination

Other coordination motor abilities which have been studied in attempt to determine the genetic endowment include space orientation and eye-hand coordination. Much of the research conducted in this area has been performed in Poland (Skład 1973, Wolański & Pyżuk 1973, Wolański & Kasprzak 1979, Szopa et al. 1985, Mleczko1991, Jaworski & Szopa 1998, Cieśla 2005, Wieczorek 2006). Below are presented the heredity indexes for space orientation obtained through family research in Poland with the use of the same apparatus.

As can be see from the table above, heredity indexes for space orientation vary from 0,14 up to 1,00. Most of the data indicate a significant genetic en-

dowment of his coordination ability. Table 8 contains results of heredity indexes for eye-hand coordination. As in case of space orientation only the latest family research data has been presented, in which the same evaluation procedures were applied.

Table 7

Heredity indexes (h^2) for space orientation estimated through family research conducted in Poland.

Age group	Cracow [1] 1981-1983			Cracow [2] 1982-1989			Kielce [3] 1995 -1996		
	S	D	G	S	D	G	S	D	G
7-10	0,55	0,33	0,44	0,28	0,41	0,30	0,14	0,18	0,16
11-14	0,84	0,41	0,62	0,32	0,37	0,39	0,54	0,16	0,35
15-19	0,63	0,54	0,59	-	-		1,00	0,34	0,67

Żywiec [4] 1995-1996			Kielce [5] 2001-2002		
S	D	G	S	D	G
0,36	0,82	0,59	0,34	0,32	0,32
0,60	0,24	0,42	0,42	0,39	0,37
-	-	-	-	-	-

Legend: S – son, D - daughter, G - general

1 - Szopa et al. (1985); 2 - Mleczko (1991); 3 - Cieśla (2005); 4 - Jaworski & Szopa (1998), 5 - Wieczorek (2006)

Table 8

Heredity indexes (h^2) for eye-hand coordination estimated through family research conducted in Poland.

Age group	Cracow [1] 1981-1983			Cracow [2] 1982-1989			Kielce [3] 1995 -1996		
	S	D	G	S	D	G	S	D	G
7-10	0,24	0,31	0,27	0,44	0,40	0,46	0,26	0,22	0,24
11-14	0,60	0,44	0,52	0,47	0,23	0,32	0,36	0,72	0,54
15-19	0,55	0,43	0,49	-	-	-	0,56	0,78	0,67

Legend: S – son, D - daughter, G - general

1 - Szopa et al. (1985); 2 - Mleczko (1991); 3 - Cieśla (2005)

Reassuming the scarce research data available on heredity of eye-hand coordination, one can state that the genetic endowment of this ability is moderate.

Kinesthetic differentiation

Among the basic coordination abilities one can also list kinesthetic differentiation with its space, time and force components. As with the other coordination abilities research data regarding the genetic endowment is scarce. The main methodological obstacle includes the application of different non standarized tests with low reliability what does not allow for definite statements and conclusions. The research of Jarosz & Wolański (1967) indicates greater similarities in movement precision of mother and daughter than in case of father and son relationship. Ljach & Starosta (2001) have observed some interesting regularities in movement differentiation during twin research. They indicate that the heredity indexes increase with the range of motion needed in a particular motor task. In movements with a low range (20-25º) the heredity index equaled 0,17, for tasks with a range of movement between 40 to 50º it equaled 0,40, while in motor tasks with a high range of movement (70 to 75º) it rose up to 0,49. Similar results were obtained by Birjukow (1976) and Iljina (1976). Very high heredity indexes (0,72-0,87) for movement differentiation were obtained by Skład, who evaluated this ability on the basis of basketball shooting efficiency. On the contrary, Szopa et al (1985) reached very low heredity indexes for this ability. For replicating close movements the indexes ranged from -0,16 to 0,19, while for distant movements these values equaled respectively -0,03 to 0,16. Ljach (2002) conducted a very interesting experiment related to the differentiation of force and time. The results indicated that the heredity index for the force component equals 0,41, while the ability to differentiate muscle tone has an slightly higher index of 0,52. The replication of movement time has a much lower heredity index which equaled 0,25. Bril (1980) has also shown a significant role of movement differentiation in sport performance and its high genetic endowment.

Remaining coordination abilities

At first it must be pointed out that much of the cited data is controversial. Most of all the evaluation procedures are questionable themselves. According to recent data many traits are located in completely different motor abilities. Research in this area has been going on continuously since 1933 (Bouchard et al 1997). McNemar (1933) while conducting research on twins related to agility, reached the following heredity coefficients: rotation movements – from 0,68 to 0,79, for sorting cards 0,43 and for winding thread on a wheel 0,29. Similar research and results were conducted by Vandenberg (1962), who showed heredity coefficients of 0,32 to 0,52 for rotation movements, sorting cards between

0,61 to 0,71 and for turning small blocks 0,05 to 0,58. On the other hand Skład (1975) reached values of this coefficient for precision ball throwing equal to 0,87 for females and 0,40 for males. Kovar (1976) in similar research, yet performed with a medicine ball obtained a coefficient of 0,60. Interesting results were obtained by Skład (1973) during a labyrinth test protocol. The heredity coefficients for females were very high and reached an average value of 0,87 while in male boys they were very low and equaled 0,08. When the number of conducted errors was considered these coefficients were 0,94 for girls and 0,52 for boys respectively. Even more complicated research with the use of a labyrinth was conducted by Kovar (1974). The motor task in his research included guiding a stick in a labyrinth with both hands. The heredity coefficients for the time of the task were 0,48 for both males and females and 0,64 for the amount of performed errors. Ljach in his research conducted on twins indicated that vestibular stability, movement amplitude replication and movement combining are abilities with a strong genetic endowment.

Conclusions

The conducted review, considering methodological faults allows for the following conclusions:

1. In general research related to the genetic endowment of coordination abilities shows higher heredity coefficients for twin studies in comparison to family studies. It must be remembered that in both methods different components of genetic variance are estimated.
2. The heredity coefficients obtained for coordination motor abilities must be interpreted with caution and related to the genetic endowment of somatic variables.
3. The highest scientific value is attributed to research conducted with a large number of subjects and with properly applied coordination motor tests (the influence of skill on test results must be eliminated).
4. The analyzed results allow to indicate a strong genetic endowment of space orientation, while moderate heredity coefficients are observed for speed of movement and eye-hand coordination. For most of the other considered coordination abilities the obtained results are highly divergent and thus it is difficult to definitely state their level of genetic endowment.
5. It is necessary to conduct further research related to the genetic endowment of coordination motor abilities in both twin and family studies with the consideration of newest methodological assumptions.

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