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Research Article

Relationship between Motor Learning and General Intelligence

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Received: February 22, 2021; **Published:** May 27, 2021

Abstract

The acquisition of skills is associated with the process of motor learning. We assume that its pace is determined by the abilities and levels of a wide range of neural processes, including intelligence. The content of the research was to find out the differences in the level of motor learning (ML) and general intelligence (IQ) in the group of 120 boys and girls of primary school and grammar school aged 12 - 17 years and the subsequent identification of a possible relationship between the two indicators. The results did not show significant differences in the level of motor learning and intelligence between the genders in either age category. Correlation analysis confirmed a significant relationship between ML and IQ excluding the gender factor (r = -0.297). When gender was taken into account, the relationship was seen only in boys (r = - 0.312) [1]. We note that we found a lower rate of ML in students with a higher level of intelligence. We observed the same tendencies in the girls, but insignificant.

Keywords: *General Intelligence; Motor Skills Learning; School Physical Education; Self-Perception*

Introduction

Man as a human being is born to move and learns how to move effectively throughout life. From the didactic point of view, the acquisition (learning) of specifically focused movements and their improvement becomes a characteristic feature of learning. In that sense, the term 'motor learning' ('ML') is generally used in the field of sport and physical education. Motor learning covers a wide range of human activities and, with its results, plays an important role in the ontogenetic development of the individual. Of course, the primary credit for motor expression is motor skills [2]. According to Fridland (2017) and Levi (2017), the standard description of learned motor manifestations formed only by motor abilities cannot be given in such a simplified way. According to them, motor control is rather intelligent throughout. Conceptually, Guadagnoli and Lee (2004) consider motor expression to be the result of two variables - skill level and task difficulty.

Motor learning is the process of transforming sensory inputs into subsequent motor outputs (Stanley and Krakauer, 2013). It is a complex process that does not take place in isolation, but with the participation of many objective and subjective factors. This process is not directly observable due to its complexity, but its products - i.e. skills are observable (Schmidt, 1991). Diagnosis of the learning process is problematic because these abilities cannot be quantified very much (Velenský, 2008) [3,4]. Every motor skill is the product of a long and often strenuous process of acquiring a whole range of stimuli. Learning complex motor behaviors like riding a bicycle or swinging a golf club is based on acquiring neural representations of the mechanical requirements ofmovement (e.g. coordinating muscle forces to control the club) (Mattar and Gribble, 2005).

Here we provide evidence that mechanisms matching observation and action facilitate motor learning.

Gandolfo., *et al*. (1996) investigated how human subjects adapt to forces perturbing the motion of their ams. They found that this kind of learning is based on the capacity of the central nervous system (CNS) to predict and therefore to cancel externally applied perturbing forces. If the actual sensory feedback differs from the predicted one, the resulting prediction error is controlled by the ML by updating the internal model. (Donchin., *et al*. 2003) [5].

It is generally assumed that the motor cortex is the basis for acquiring and performing motor skills. have confirmed the role of the brain, resp. cortical-basal ganglia circuits in motion control (Wooley and Kao, 2015). To understand the role of the cerebellum in motor control, it is helpful to consider neuroanatomical evidence showing that distinct regions of the cerebellum are concerned with specific motor functions, giving rise to concept of "compartments" of motor functions within the cerebellum [6] (Paulin, 1993; Konczak and Timmann, 2007).

In the study of motor learning control, we encounter questions of the functioning of the neuromuscular system, its activation and coordination of muscles and limbs involved in the performance of motor skills, which Magill and Anderson (2014) unify with the term - motor control. It includes the whole system of perceptual factors - perception of oneself and the environment, maturation, motivation, social motives, anxiety, stress and other forms of tension involved in interacting with classmates and the teacher. In the theory of motor learning we also find the term - working memory. The concept of working memory assumes that a limited capacity system temporarily stores information and thereby supports human thought processes (Baddeley, 2003) [7,8]. One prevalent model of working memory comprises three components: a central executive, a verbal storage system called the phonological loop, and a visual storage system called the visuospatial sketchpad. When realizing the movement itself, the visual model is compared with the planned movement. We observe this phenomenon e.g. at the high jumper. He visualizes his movement in advance (comparison with the model) and only then executes it by the executive body (Pollock and Lee, 1992). However, a prerequisite for correlation analysis is an understanding of the determining factors. While infants acquire skills through imitation and trial and error, we follow the rules in formal teaching. In supervised motor learning, where the desired movement pattern is given in task-oriented coordinates, one of the most essential and difficult problems is how to convert the error signal calculated in the task space into that of the motor command space (Kawato, 1990). From a conceptual point of view at ML, we also encounter behavioral theories that understand motor skills as a consequence of the manifestation of the entire spectrum of mental processes. Ivry (1996) considers psychological processes to be factors that allow past experience to be used to improve motor behavior. According to Wolpert, Ghahramani and Flanagan (2001), learning involves changes in behavior that result from interaction with the environment. It has also been shown that information on the high level and form of movements can also be obtained by observing others (Petrosini., *et al*. 2003). However, these processes are not sufficiently clarified in terms of motor learning in sport. At present, the role of cognitive processes in motion control is also not sufficiently stressed. The important role of perception as a factor that has a significant influence on the time characteristics of the realization of the movement and thus on its overall quality is not emphasized [9-12]. (Horička, Šimonek, and Paška, 2020). Current research confirms evidence of some correlations between basic categories of motor and cognitive abilities, including complex motor skills and higher order cognitive abilities (Raiola, 2017; van der Fels., *et al*. 2015).

Taking a broader view of the position of cognition in the procedural side of movement, we must also consider the role of intelligence and a common center of control of these processes - the nervous system. According to Piaget (1964), intelligence is a form of mental organization, and the largest form of management of cognitive structures. It integrates forms of behavior and thus a large number of specific skills (speed of processes, attention, etc.).

Materials and Methods

Design

Until the beginning of the research, pupils and students did not complete the thematic unit of gymnastics with selected gymnastic elements, which formed the content of the ML test. 15 boys and 15 girls from each form took part in testing the level of motor learning and intelligence. All research participants confirmed in writing their consent to their inclusion in the research and to the processing of personal data in accordance with the EU GDPR Regulation [13-15].

In 3 practice classes, students performed a methodical series of exercises, exercises to master individual positions, and finally followed the combination of individual activities to demonstrate the whole movement. After each training lesson (n = 3/45´), we evaluated the level of ML in boys and girls in the demonstration of learned gymnastic elements using a grade from 1 to 5, with grade 1 corresponding to the best grade and grade 5 to the worst [16]. The gymnastic element of the pupils of the 6th form was a roll forward to the crotch stand, for the pupils of the 7th form it was a roll back to the crotch stand, for the students of the 1st form of high school it was a stand on the head and for the 2nd form students it was a cartwheel. Assessment was performed independently by 2 qualified P.E. teachers.

Participants

The monitored group for comparing the level of motor learning and intelligence were pupils of the 6th form (decimal age DA = 11.78 y.), 7th form (DA = 12.96 y.), 1st form (DA = 15.94 y.) and 2nd form of Secondary Grammar School in Nitra, Slovakia (DA=16.85 y.; table 1) [17,18].

Grade	Decimal age	Body height/cm		Body weight/kg	
	Years	Boys	Girls	Boys	Girls
6th ES	11.78	151	154.3	41.8	44.2
7th ES	12.96	160.2	156.6	47.8	46.3
1st SGS	15.94	173.1	165.8	62.8	54
2nd SGS	16.85	176.4	168.7	70.9	55.3
$\bar{x}$	14.38	165.2	161.4	55.8	50

Table 1: *Basic somatometric indicators.*

Explanatory notes: ES: Elementary School; SGS: Secondary Grammar School.

Testing procedures

We used the Azzopardi (1989) intelligence test to determine the level of general intelligence. It consists of 2 intelligence tests, each with 20 questions. The time limit is 20 minutes to develop one test immediately followed by another test with the same number of questions and the same time limit. The resulting score was the sum of the correct answers from both tests. The levelof motor learning was evaluated using the method of professional assessment. To obtain the necessary material for the solution, we used anthropometric measurements, observation method, expert assessment [19].

Statistical analysis

The normality of the primary data was determined using the Shapiro-Wilk test, the degree of statistical significance by the Mann-Whitney test, and the magnitude of the differences by the Effect size method. A non-parametric Spearman correlation coefficient rs (correlation analysis) was used to determine the dependence of the quantitative features. Statistical processing of primary data was carried out using the Software IBM SPSS (version 24) [20-22].

Results

The basic characteristics of the position are given in table 2. At the ML level, we observe relative stability and a slight decrease in values for middle-school students (girls: 1.95 > 1.89 ML level), similarly for boys (2.24 > 2.19 ML level). Subsequently, in older school age, this ability is dynamized in both sexes, the level of ML reaches the value of $ML\bar{x}_b$ = 2.51 in boys and 2.42 in girls. Overall, we evaluate the level of ML in boys ($ML\bar{x}_b$ = 2.33) higher than in girls ($ML\bar{x}_g$ = 2.08), the difference decreases with increasing age (Figure 1). When evaluating the material significance of the differences, we state the dominance of boys, especially in the 7th grade of primary school (Cohen´s d = 2.14) [23,24].

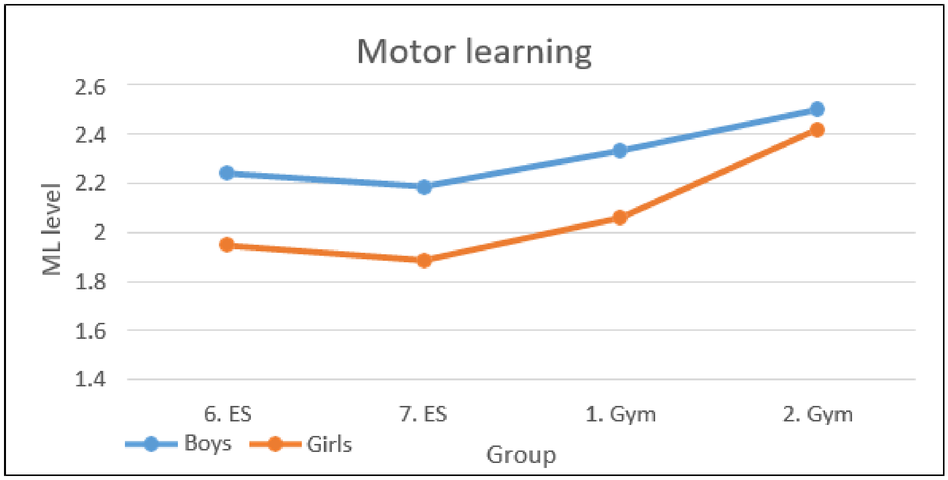

Figure 1: *Motor learning level - boys vs girls.*

The difference between the genders was small (p = ⟨0.19 - 0.81⟩) and statistically insignificant. The hypothesis that the performance dominance of boys over girls is also reflected in ML has not been confirmed in any age category [25]. This statement is also supported by the values of materiality of differences (Effect size) d = ⟨0.046 - 0.24⟩. Since the null hypothesis H0 and also the small effect size was confirmed, we can say with certainty that we did not notice any differences between the samples (Table 2).

Motor learning	6^{th} form ES		7^{th} form ES		1^{st} form SGS		2^{nd} form SGS	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
Mean	2.24	1.95	2.19	1.89	2.33	2.06	2.5	2.42
Std. Error	.16	.11	.17	.16	.18	.15	.23	.12
Median	2.3	2	2	2	2.3	2	2.7	2.3
Std. Deviation	.64	.43	.67	.63	.71	.59	.88	.47
Minimum	1	1.3	1.3	1	1	1	1	1.7
Maximum	3.3	2.7	3.3	3	3,3	3	3.7	3.3
Sum	33.6	29.2	32.8	28.3	35	30.9	37.5	36.3
Sig. (2-tailed)	.187		.267		.285		.806	
Sign.	p > .05		p > .05		p > .05		p > .05	
Cohen´s d	.24*		.21*		.20*		.046*	

Table 2: *ML level in the sample of students.*

*Explanatory notes: ES: Elementary School, SGS: Secondary Grammar School, *: Small Effect Size.*

When evaluating the level of intelligence with respect to gender, on the contrary, we state a slight predominance of girls ($I\bar{x}g$ = 112.75) over boys ($I\bar{x}b$ = 112). In both sexes, from 12 years to 17 years of age, the IQ value increases continuously from the level of 107.1 to 116.4 points (boys) and from the value of 108.2 to 116.7 points (girls). This finding proves that intelligence is not dependent on gender. Gender differences in IQ levels decrease with age. Table 3 shows the values of descriptive statistics and the significance of differences - IQ in the monitored samples (Figure 2).

Intelligence	6th form ES		7th form ES		1st form SGS		2nd form SGS	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
Mean	107.1	108.2	109	112.1	114.9	113.9	116.4	116.7
Std. Error	1.26	1.40	1.38	1.04	1.73	1.62	1.48	1.70
Median	107	108	108	113	115	114	118	118
Std.	4.89	5.41	5.35	4.03	6.71	6.29	5.76	6.62
Minimum	98	98	102	105	103	105	105	105
Maximum	115	117	119	119	127	125	124	127
Sum	1606	1623	1635	1682	1723	1709	1746	1750
Count	15	15	15	15	15	15	15	15
Sig. (2-tailed)		.539	.089		.713		.935	
	p > .05		p > .05		p > .05		p > .05	
Cohen´s d	-.11*		-.31*		.064*		.011*	

Table 3: *IQ level in the sample of students.*

*Explanatory notes: ES: Elementary School; SGS: Secondary Grammar School; *: Small Effect Size.*

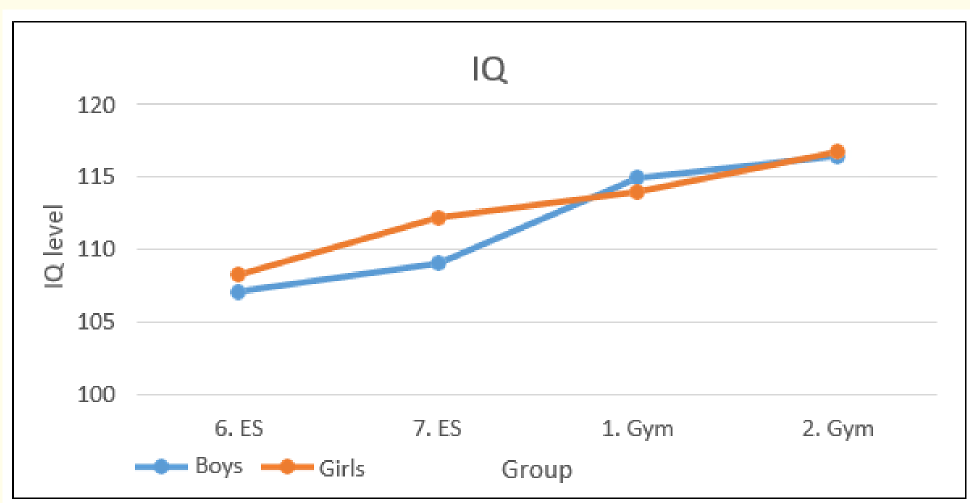

Figure 2: *IQ level - boys vs girls.*

Also, in the case of IQ analysis in relation to gender, no statistically significant difference was found between boys and girls p = ⟨0.089 - 0.935⟩. The statement is also supported by low values of Effect size - Cohen´s d = ⟨-0.31 - 0.064⟩ [26].

Differences in IQ levels were smaller between boys and girls than in the case of ML, but the fact that both indicators were measured in different units should be taken into account.

The subject of the correlation analysis was first to assess the existence and extent of a possible relationship between the factors of intelligence and motor learning regardless of the gender, and with regard to gender. The relationship between the two indicators was confirmed with the exclusion of the gender factor (r_s = - 0.297, sig. < 0.1), but the tightness of the relationship is low. Taking into account the gender of the probands, the relationship was confirmed in the monitored indicators only in boys (r_s = - 0.312, sig. < 0.5), in girls, a significant relationship was not confirmed (r_s = - 0.225, sig. > 0.1; table 4). Due to the extent of the monitored group (n = 120), a weak dependence with a value of r_s < 0.3 may be statistically significant. We therefore evaluate the degree of dependence between the variables as relatively low.

Correlations			ML	IQ	ML boys	IQ boys	ML girls	IQ girls
Spearman's rho	ML	Corr.	1.000	-.297**	1.000	-.312*	1.000	-.225
		Sig. (2-tailed)		.001		.015		.083
	IQ	Cor. Coefficient	-.297**	1.000	-.312*	1.000	-.225	1.000
		Sig. (2-tailed)	.001		.015		.083	
		N	120	120	60	60	60	60

Table 4: *Correlation between motor learning and intelligence.*

***: Correlation is significant at the 0.01 level (2-tailed).*

**: Correlation is significant at the 0.05 level (2-tailed).*

The negative polarity of correlation coefficients and their distribution indicates the antagonistic relationship of the observed indicators. The level of motor learning decreases with increasing intelligence in both genders, but we must interpret this relationship very carefully, especially in relation to the statistical degree of the relationship between these factors (Figure 3).

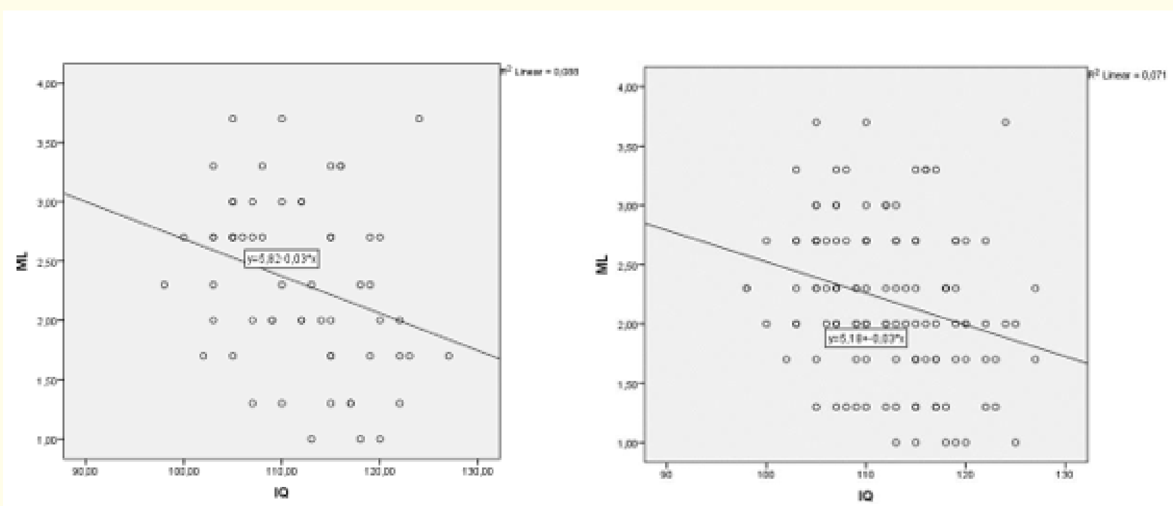

Figure 3: *Relationship between ML and intelligence level (boys and girls).*

In the analysis of the factor in relation to gender, no significant relationship was found in the case of boys or girls (ML r_s = - 0.163, sig. > 0.5; IQ r_s = 0.071, sig. > 0.5; table 5). Thus, the observed factors are not dependent on gender, but are probably determined by other factors. The overall difference in the level and dynamics of the development of ML and IQ with respect to age is confirmed by the degree and polarity of the material significance of the differences. (Effect size; d_{ML} = 1.08; dIQ = -0.46) [27].

Correlations			ML	Gender	IQ	Gender
Spearman's rho	ML	Correlation	1.000	-.163	1	.071
		Sig. (2-tailed)		.075		.44
	Gender	Correlation	-.163	1.000	.071	1.000
		Sig. (2-tailed)	.075		.44	
		N	120		120	
			ML boys/girls		IQ boys/girls	
	Effect size/Cohen´s d		1.08		-0.46	

Table 5: *Correlation between motor learning and intelligence.*

Discussion

Based on the hypothesis of the dominance of boys in terms of the pace of motor learning in a selected group of school population of boys and girls, the differences in favor of boys were not confirmed in any of the monitored age categories. Higher values were recorded in boys, but the differences were not statistically significant (p = ⟨0.19 - 0.81⟩). In both genders, the dynamics of ML are similar, but not ascending. In the 7th year, the ES even declines slightly. The gender gap gradually decreases with increasing age. The intervals of ML values were in boys $\bar{x}$ = ⟨2.19 - 2.51⟩, u dievčat $\bar{x}$ =⟨1.89 – 2.42⟩.

When assessing the level of IQ, the tendencies are different in terms of gender. At the age of 11-13 years, girls $\bar{x}$ = ⟨IQg 108.2 vs IQb 107.1⟩ slightly dominate, at the beginning of adolescence at the age of 15 again boys $\bar{x}$ = ⟨IQb 114.9 vs IQg 113.9⟩ and at the age at 17 years, the differences are at least $\bar{x}$ = ⟨IQb 116.4 vs IQg 116.7⟩. The differences are also statistically insignificant in the case of IQ. The relationship analysis showed only a low relationship between the parameters ML and IQ with the exclusion of the gender factor ((rs = -0.297, sig. < 0.1), taking into account the gender confirmed the relationship between the parameters only in boys (rs = - 0.312, sig. < 0.5) [28]. We interpret the rate of motor learning in boys and girls as the IQ values decrease with increasing IQ values, and we assume that this relationship will be more pronounced at extreme IQ values. It is different from motor skills, it is limited by the cultural and social environment, while the process of motor learning is determined by teaching methods and didactics. Our results confirm that more than intellectual abilities, the pace of acquiring abilities and skills is limited by the procedural side of teaching.

Conclusion

Following the above facts about the theory of motor control and our findings, we assume the continuity of certain mental and motor processes, which Berendsen., *et al*. (2009) call motor intelligence. This relationship has been confirmed in many studies. Planinšec and Pišot (2006) present the findings that adolescents with average intelligence performed motor coordination tasks more effectively than adolescents with below-average intelligence. Similarly, Thompson and Witryol (2010), Smits-Engelsman and Hill (2012), Engelsman and Hill found that individuals with lower measured IQs were more likely to show poorer motor performance than individuals with higher measured IQs. Paunescu., *et al*. (2013) found statistically significant correlation (r = 0.76; n = 40; p < 0.001) between general intelligence and motoric intelligence specific to combat sports, in a group of subjects who do not practice performance sports. Students with higher level of general intelligence also prove superior motoric abilities within the process of motor skills development [29].

The results of our research did not show significant differences in the level of ML and IQ in both genders. Boys slightly dominated in ML, girls in IQ in accordance with Ramakrishnan (2018), this difference decreases with increasing age. Thus, motor ontogenesis probably proceeds at a different rate than mental in relation to gender. There was also no relevant relationship between the ML level and general IQ. It was confirmed only in the group of boys, but only to a small extent. This fact could be caused by several factors: the age and performance structure of the sample, the validity of the diagnostic procedure, inappropriate time interval of training of the evaluated element, the type of intelligence detected, or even insufficient motivation. Our findings are in line with the research results by Cushing, (1968), who did not find any relevant relationship between motor educability (Iowa-Brace Test) and mental maturity (California test) on a sample of female school population (5th grade). However, the dynamic social development of mankind relativizes these results nowadays.

We consider it necessary to clarify the nature of the possible relationship of these properties in a broader context in order to improve the quality of motor learning. It is necessary to abandon the claim that skills are soulless or merely physical. On the contrary, we argue that movement is a manifestation of the association of motor functions and cognitive processes, the cultivation of which in the process of learning skills must take place simultaneously. Finally, learning is the only fast enough mechanism that allows us to cope with new tasks that are specified by societal tasks. Finally, the "learn to learn" competence is also one of the 8 key competences for lifelong learning, in line with the European Commission's Recommendation 2006/962 (OJ L 394, 2006) [30].

Conflict of Interest

The authors declare no conflicts of interest. We certify that no party having a direct interest in the results of the research supporting this article has or will confer a benefit on us or on any organization with which we are associated.

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Volume 12 Issue 6 June 2021