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Relationships between Cognitive and Motor Abilities in Female Children Aged 10–14 Years

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A B S T R A C T

The aim of the study was to determine cognitive and motor status factors in female children aged 10–14 years and to identify developmental and/or integration functions according to age. The study included a sample of 162 female schoolchildren aged 10–14 years divided into two groups: 84 girls aged 10–12 (X 11.26, SD 0.68) years and 78 girls aged 13–14 (X 13.52, SD 0.63) years. Study results showed a statistically significant between-group difference in the overall system of variables (MANOVA), with the level of significance determined for each individual variable (ANOVA). The older group of subjects showed significantly superior results in comparison with the younger group in the motor tests assessing flexibility, agility, psychomotor speed, explosive strength of throwing type and repetitive strength of the trunk, as well as in the test assessing cognitive functioning. Qualitative differences between the two age groups (prepubertal and pubertal) were determined by use of the matrix of variable inter-correlations factorized by the procedure of principal components that were then transformed to promax solution. The results thus obtained indicated cognitive functioning to take significant part in the motor efficacy of girls aged 10–14 years. In the younger age group (10–12 years), cognitive functioning was related to the motor system that integrates muscle tone regulation and agility/coordination. In the older age group (13–14 years), cognitive functioning was involved in the formation of the first and third factor isolated, i.e. in the factor regulating coordination and intensity of energy mobilization of lower extremities (general motor efficiency) and, to a lesser extent, in third factor regulation the intensity of energy mobilization of upper extremities and trunk strength.

Key words: *schoolgirls, age 10–14 years, cognitive-motor structures*

Introduction

Based on a number of studies, Ismail and Gruber have developed the theory of integral development, according to which there is an association of the person's morphological, motor, cognitive and conative dimensions[1–4]. The brain areas that are involved in motor tasks and learning are closely inter-related. These areas are activated and the central nervous system is regenerated by regular physical activity. Furthermore, learning complex motor structures activates prefrontal cortex, which is also active on solving mental problems, thus favorably influencing subsequent learning. Motor activity in general, and especially in the period of growth and development, should be an integral part of the educational process for its beneficial effects on the complete bio-psycho-social status of children. Regular physical activity has manifold favorable effects on the overall children's development, therefore motor activity by itself, along with determination of the motor space structure and of motor space relationships with other individual's dimensions, is an important segment of developmental process research.

Previous studies have generally confirmed the existence of significant positive correlations between motor and cognitive abilities, which increase with the motor task complexity and decrease with age[5,6]. Studies including adolescents, and more rarely small children, pointed to the relationship of complex motor tasks and intelligence. However, there are reports on the correlation of intelligence and speed of simple movements, equilibrium, agility and explosive strength[6,7].

Studies have established the existence of positive correlation between intelligence and performance of complex motor tasks, and by analogy with specific motor skills in various sports. This relationship is explained by

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the speed of general information processing in the central nervous system and involvement of cognitive processes in motor activity. Cognitive processes and cognitive functioning are the central mechanisms of cortical regulation. Central nervous system has primarily integrative function and enables purposeful and adjustable behavior in humans. Integration at the cortical level is of utmost importance because purposeful behavior is directly related to the integrative function of the cerebral cortex. Integration also exists at the subcortical level, especially in the situations that require automated reactions. Luria (1973)[8] has demonstrated that tertiary zones of the cerebral cortex play a major role in providing simultaneous (spatial) syntheses and involve cortical areas of the visual, auditory, vestibular and tactile-kinesthetic analyzer. Semmes (1968)[9] reports that the left hemisphere favors coupling of similar units into information, while the right hemisphere favors integration of dissimilar units. Ismail and El-Naggar (1981)[10] emphasize that both successive and simultaneous processes, including the left and right brain hemispheres, are present on performing motor coordination tasks. In a sample of high-school students, Katić (1977)[11] found a high positive correlation of the coordination, speed and explosive strength test performance with the results achieved in the tests of visual spatialization (simultaneous processor) and perceptive reasoning (perceptive processor). Investigating relationships of motor abilities and knowledge of school subjects in high-school students, Katić (1988)[12] found the success in physical education to depend significantly on the function of the simultaneous (parallel) and perceptive as well as serial processor in both male and female students.

There are various theories[13,14] on all elements that are necessary in the creation of a motor program. Task length and structure are the two main characteristics that influence the process of motor program designing. When a child is acquiring a motor program (motor knowledge or skill), he/she starts doing it at a cortical level; as the program is being increasingly mastered and acquired, it is gradually done at subcortical level.

Accordingly, cognitive functions that are dependent on the level of integration of the mechanism for the information receipt, transfer and decoding in the central nervous system are related to the mechanisms of the motor regulation of movement. As many motor behaviors are complex and contain cognitive behavior to a certain extent, it is presumed that the same and/or similar mechanism are responsible for the motor and intellectual behavior of man.

Relationships among the subsegments of the anthropologic system are very complex and can only be explained by thorough knowledge of the biological developmental functions that proceed differently according to sex in a particular developmental phase for each individual variable of the morphological, motor and cognitive spaces. In particular developmental phases, the sex specific processes of differentiation and integration occur alternately within and between the morphological, motor and cognitive spaces[15–18]. Studies conducted in elementary school first-graders have shown the process of integration of aerobic endurance and coordination into the morphological-motor system to occur earlier, i.e. faster in female as compared with male children, along with earlier formation of the factor of general motor efficiency defined by coordination as well as by the force and speed regulators. Force regulation is related to simultaneous (parallel) information processing, as in performance of motor tests of long jump and polygon backward, while speed is related to serial processing of information, as in performance of hand tapping and one-minute crossed-arm sit-ups[16]. Each movement integrates force and speed, while the superior mechanism regulates the force to speed relations for the movement to be efficient. The superior mechanism is responsible for solving not only motor but also cognitive problems.

Each stimulus received probably undergoes a double process, successive and simultaneous, while the degree of inclusion of either depends on the nature of the stimulus and task requirements, as well as on the personality traits. Female sex is believed to be superior in verbal reasoning in terms of numerical reasoning, which may favor higher activation of the successive process relative to simultaneous process in the nervous system. In addition, communication between the brain hemispheres plays an important role in stimulus performance.

Raven's Standard Progressive Matrices (RSPM)[19] offer a very useful test tool for assessment of cognitive status in children and adolescents (age ≥11 years), while Raven's Colored Progressive Matrices are used on assessment of cognitive status in preschool and young schoolchildren[20]. It is a nonverbal test intended for g-factor measurement according to classic Spearman's terminology[21,22]. The SPM test-retest reliability was found to be as high as 0.96[23].

Mackintosh and Bennett (2005)[24] performed brain scanning during RSPM testing and found light items to activate right hemisphere, right frontal lobe in particular, while more difficult (analytical) items activated left hemisphere, *i.e.* left frontal lobe.

Milner and Goodale (1995)[25] also distinguish ventral and dorsal systems, with the output differing between the two systems. Ventral system is intended for perception and dorsal system for action control, not for perception. That is why they call the latter the »how« system. Finally, Glover (2002, 2004)[26,27] proposes classification into systems of planning and control in visuomotor activity, whereby planning uses information from the ventral, *i.e.* perceptive, »what« system, whereas on-line control derives information from the dorsal, spatial, »where/ how« system.

Chabris et al. (2006)[28] report on male science students and those who like computer games to prefer spatial visualization (visuospatial intelligence), whereas female humanist students and artists prefer object visualization (verbal intelligence). The individuals with spatial style are superior in mental rotation and labyrinth tasks, while those with object style are superior in complex object recognition. Based on higher correlations, the authors conclude that spatial visualization must be a more unified and homogeneous ability.

It appears that the old psychological classification into verbal and nonverbal intelligence has a neurophysiologic basis. Provided that nonverbal intelligence is termed »visuospatial« intelligence, thereby having in mind the association of visuospatial cognition with motor planning and control, then perception requires action (according to Gallese, 2007)[29].

The main problem of this study was to identify and define the factors responsible for cognitive and motor development of female children from age 10 to age 14, and the factors responsible for the age specific integrative processes of the cognitive and motor status.

Materials and Methods

Study subjects

The sample was drawn from the population of female schoolchildren in the city of Split, Croatia. The study included a sample of 162 female schoolchildren aged 10–14 years, divided into two groups:

- 84 girls aged 10–12 (X 11.26, SD 0.68) years, and
- 78 girls aged 13–14 (X 13.52, SD 0.63) years.

Instruments

A battery of 11 motor tests used in this study was selected on the basis of experience in adult subjects. These tests estimate the effectiveness of the following functional mechanisms: movement structuring, tone and synergetic regulation, regulation of excitation intensity, and regulation of excitation duration[30]:

- to estimate functional coordination of primary motor abilities:
  1) Steps laterally,
  2) Obstacle course backwards;
- to estimate balance:
  3) Board balance;
- to estimate flexibility:
  4) Seated straddle stretch;
- to estimate frequency of simple movements:
  5) Arm plate tapping,
  6) One foot tapping;
- to estimate explosive strength power:
  7) Standing broad jump,
  8) 20-m dash,
  9) Medicine ball throw from supine position;
- to estimate repetitive strength of the trunk:
  10) Crossed-arm sit-ups;
- to estimate static strength of arms:
  11) Bent-arm hang.

A short description of the motor tests is given below:

1) *Steps laterally.* The subject had to cross a 4-m distance with lateral steps as fast as he/she could. The score was the time of running measured in tenths of second.
2) *Obstacle course backwards.* The subject had to walk fast backwards on all fours and cover a 10-m distance, climb the top of the Swedish bench and go through the frame of the bench. The task was measured in tenths of second.
3) *Board balance.* A wood balance rail 4 cm high, 2 cm wide and 30 cm long was fastened in the center of a 60×30 cm board. The subject balanced on the rail, with his/her hands on his/her hips, using the preferred foot with the long axis of the rail in parallel to the long axis of his/her foot. The subject determined the starting signal. When he/she felt he/she had balance he/she said »GO«, and the tester started a stop watch. The time ended when the subject touched the floor with any part of his/her body, or when he/she removed either hand from his/her hips. The subject's score was the length of time he/she held his/her balance.
4) *Seated straddle stretch.* The subject sat on the floor, leaning against the wall, in straddle position and bows forward as far as possible. A straight-angle ruler lied down in front of the subject and he/she reached the scale with cm as far as he/she could. The result was the depth of the reach measured in cm.
5) *Arm plate tapping.* For fifteen seconds the subject had to tap alternately two plates on the tapping board with his/her dominant hand, while holding the other hand in between the two plates. The result was the number of cycles (alternate double hits) completed in 15 seconds.
6) *One foot tapping.* The subject sat on a chair, placing his/her preferred foot next to a board 45 cm long. A 15-cm perpendicular partition was in the center of the board. On the signal »GO«, the subject lifted his/her foot over the partition and tapped the board on the other side. Then, he immediately lifted and returned his/her foot over the partition and tapped the board on the starting side. This was counted as one cycle. The subject's score was the number of cycles completed in 15 seconds.
7) *Standing broad jump.* The subject jumped with both feet from the reverse side of Reuter bounce board onto the carpet, which was marked in cm. The result was the length of the jump in cm.
8) *20-m dash.* On command »GO« the subject standing behind the start line had to run 20 m as fast as he/she could to the end of the track (20 m). The subjects ran in pairs. The score was the time of running measured in tenths of second.
9) *Medicine ball throw from supine position.* The subject lied supine (on his back) so his/her outstret-

ched arms were behind his/her head, grasped the medicine ball with his/her palms on each side. The medicine ball was on the base line. The subject had to throw the ball as far as possible. Score was the distance of the throw from the base line to the point where the ball touched the ground, measured in meters.

10) *Crossed-arm sit-ups*. The subject lied on his/her back with his/her knees bent and arms crossed on the opposite shoulder. He/she rose into seated position and returned into starting position. The instructor's assistant held the subject's feet. The result was the number of correctly executed raises to seated position (no longer than 60 seconds).

11) *Bent arm hang*. The subject under-gripped the bar and held the pull-up as long as he/she could (with the chin above the bar). The result was the time of the hold measured in tenths of second.

Raven's SPM test consisting of 5 sets (A, B, C, D and E) of 12 tasks each was employed for assessment of the study subjects' cognitive status. According to Van der Ven and Ellis (2000)[31], the A, C and D sets are one-dimensional, while the B and E sets are not. Lynn et al. (2004)[32] conclude that, although yielding three factors on the first order, SPM yield g-factor on the second order. According to the cybernetic models of intelligence, the component of planning, deciding and target management is one of the components of the central information processing[33,34].

Data analysis

Basic statistical parameters were calculated for both groups of study subjects *per* variable (mean and standard deviation). The significance of quantitative differences in the overall space of variables was defined from the results of multivariate analysis of variance (MANOVA), and for each individual variable from the results of univariate analysis of variance (ANOVA).

Qualitative differences were analyzed from the results of factor analysis by factorization of the matrix of variable inter-correlations using Hotelling method of principal components and Guttman-Kaiser criterion for determination of the number of significant principal components, i.e. factors. The initial solution was transformed to oblique solution, which enables inter-correlations among the factors by use of promax solution. Qualitative differences between the two age groups (10–12 and 13–14 years) were analyzed from the structure of the factors obtained and their inter-correlations, with special reference to the factors characterized by significant saturation of the cognitive variable.

Results

Means (X) and standard deviations (SD) of all variables for both age groups are presented in Table 1. The same table shows the most important results of multivariate (F and P) and univariate (f and p) analysis of variance, which revealed a statistically significant difference between the two study groups in the overall system of variables (F=6.38, P=0.00). Significance was tested by a number of criteria (Pillai's Trace, Wilks' Lambda, Hotelling's Trace and Roy's Largest Root), all of them indicating a high level of significance.

Upon determination of the statistically significant between-group difference in the overall system of variables, the level of significance was determined for each individual variable. Results of this analysis pointed to statistically significant differences in 6 motor variables and the variable assessing cognitive functioning, in favor of older age group (Table 1). The older age group had significantly superior results than younger age group in motor

TABLE 1
BASIC STATISTICS AND DIFFERENCES OF VARIABLES IN GIRLS AGED 10–12 AND 13–14 YEARS

Variable	10–12 years		13–14 years		f	p
	X	SD	X	SD		
Steps laterally (s)	11.19	1.02	10.43	1.08	21.36	0.00
Obstacle course backwards (s)	14.57	3.39	14.09	3.87	0.69	0.40
Board balance (s)	7.21	5.02	6.39	5.39	1.02	0.31
Seated straddle stretch (cm)	57.36	12.95	68.28	12.50	29.70	0.00
Arm plate tapping (freq.)	29.13	3.19	31.22	3.61	15.19	0.00
One-foot tapping (freq.)	19.01	1.78	20.00	2.37	9.06	0.00
Standing broad jump (cm)	157.93	19.83	160.60	20.05	0.72	0.39
20-m dash (s)	4.43	0.33	4.39	0.58	0.30	0.58
Medicine ball throw from supine position (m)	4.10	0.90	4.53	0.73	10.56	0.00
Crossed-arm sit-ups (freq.)	21.12	4.05	22.85	3.57	8.22	0.00
Bent-arm hang (s)	13.91	12.43	15.66	12.18	0.81	0.36
Raven's Progressive Matrices (points)	44.10	7.36	46.76	6.96	5.56	0.02
		F=6.38			P=0.00	

tests assessing flexibility, agility, psychomotor speed, explosive strength of throwing type and repetitive strength of the trunk, and in parallel to these in the test assessing cognitive functioning.

Upon determination of quantitative differences, it was necessary to determine qualitative differences between the two age groups as well, in particular because they included female children of prepubertal and pubertal age. The matrix of variable inter-correlations was calculated and factorized by the procedure of principal components (H) using Hotelling's procedure, while the significant principal components were defined on the basis of Guttman-Kaiser criterion. The significant principal components (H) and communalities (h^2) for female children aged 10–12 years are presented in Table 2.

The structures of the four principal components thus isolated explained 63.18% of the overall variability of the study variables. The first as the most relevant component explained 30.70% of this variability, however, its structure is not easy to define, which also holds for other components. Therefore, the principal components were transformed into promax solution and the factors thus isolated were interpreted on the basis of their complexes, structure and inter-correlations (Tables 3 and 4).

The following variables exerted highest projections upon the first promax factor (PATTERN MATRIX) (Table 3): Bent arm hang – assessing static strength of upper extremities and/or muscle endurance; Arm plate tapping – assessing the speed of frequency of hand movements; Obstacle course backwards – assessing whole body coordination; and 20-m dash and Standing broad jump – as-

TABLE 2
PRINCIPAL COMPONENTS IN GIRLS AGED 10–12 YEARS

Variable	H1	H2	H3	H4	h^2
Steps laterally	–0.72	0.07	–0.27	0.11	0.62
Obstacle course backwards	–0.79	0.13	0.19	–0.04	0.68
Board balance	0.07	0.77	0.17	–0.40	0.80
Seated straddle stretch	0.31	–0.53	0.41	–0.06	0.56
Arm plate tapping	0.49	0.29	–0.42	–0.05	0.51
One-foot tapping	0.27	0.52	0.34	0.10	0.48
Standing broad jump	0.82	0.11	0.16	–0.17	0.75
20-m dash	–0.79	0.13	0.19	–0.04	0.68
Medicine ball throw from supine position	0.15	0.31	0.48	0.51	0.62
Crossed-arm sit-ups	0.53	–0.16	–0.05	0.63	0.72
Bent-arm hang	0.62	0.11	–0.47	0.07	0.63
Raven's Progressive Matrices	0.28	–0.49	0.20	–0.38	0.52
Eigen value	3.68	1.67	1.14	1.07	
% of Variance (total=63.18)	30.70	13.97	9.55	8.95	

TABLE 3
PATTERN AND STRUCUTRE MATRICES IN GIRLS AGED 10–12 YEARS

Variable	Pattern matrix				Structure matrix			
	1	2	3	4	1	2	3	4
Steps laterally	–0.28	–0.52	–0.16	–0.08	–0.60	–0.70	–0.45	–0.10
Obstacle course backwards	–0.75	–0.18	0.07	0.18	–0.78	–0.50	–0.31	0.14
Board balance	0.06	–0.16	0.18	0.85	0.12	–0.09	0.19	0.86
Seated straddle stretch	–0.26	0.77	0.06	–0.22	0.10	0.67	0.15	–0.25
Arm plate tapping	0.83	–0.30	–0.16	0.12	0.62	0.03	0.14	0.17
One-foot tapping	–0.01	–0.08	0.59	0.37	0.24	0.08	0.58	0.39
Standing broad jump	0.49	0.38	0.13	0.22	0.75	0.65	0.49	0.25
20-m dash	–0.62	–0.31	0.02	–0.08	–0.76	–0.58	–0.35	–0.11
Medicine ball throw from supine position	–0.28	–0.09	0.88	–0.02	0.08	0.03	0.72	0.00
Crossed-arm sit-ups	0.39	–0.08	0.42	–0.57	0.51	0.22	0.55	–0.52
Bent-arm hang	0.94	–0.24	–0.17	–0.09	0.74	0.13	0.18	–0.03
Raven's Progressive Matrices	–0.06	0.76	–0.32	–0.03	0.13	0.63	–0.12	–0.06

TABLE 4
FACTOR CORRELATION MATRIX IN GIRLS AGED 10–12 YEARS

Factor	1	2	3
1. Mechanism for integration of force, speed and coordination			
2. Mechanism for integration of muscle tone, agility and cognitive ability	0.46		
3. Mechanism for regulation of muscle explosive strength of upper extremities	0.46	0.29	
4. Mechanism of synergistic regulation	0.06	–0.02	0.04

sessing explosive strength (sprint and jump type). This factor defines general motor efficiency of prepubertal female children, which is underlain by the complex integrating muscle endurance and speed of upper extremity movements, whole body coordination and explosive strength of lower extremities. This first factor is underlain by cortical regulation of movement, as also indicated by the structure of this factor in the structure matrix. The factor is named the mechanism of force, speed and coordination integration.

The second promax factor is predominantly defined by the following three variables: Seated straddle stretch – assessing muscle tone; Raven's Progressive Matrices – a test assessing general cognitive factor; and Steps laterally – assessing the factor of coordination/agility. The second promax factor is underlain by the integration of muscle tone regulation and agility (predominantly occurring at subcortical level) with general cognitive ability. This factor is named the mechanism of muscle tone, agility and cognitive ability integration.

The third promax factor is predominantly defined by the variable assessing explosive strength of throwing type (Medicine ball throw from supine position), which is significantly saturated by the abilities of the speed of lower extremity movements and repetitive strength of the trunk. This factor is named the mechanism of regulation of upper extremity explosive strength.

The fourth promax factor is predominantly defined by the variable assessing equilibrium, which is underlain by the mechanism of synergistic regulation and to a certain extent counteracted by the development of repetitive strength of the trunk. This factor is named the mechanism of synergistic regulation.

Inter-correlations among factors (Table 4) indicate that motor functioning in girls aged 10–12 years can be reduced to the function of the following three mechanisms: mechanism responsible for the integration of force, speed and coordination; mechanism responsible for the integration of muscle tone, agility and cognitive ability; and mechanism responsible for the regulation of muscle explosive strength of upper extremities. There is significant correlation between the first and third factors, whereby the force regulator is saturated by coordination and speed of upper extremity movements in the first factor, and by the speed of lower extremity movements and strength of the trunk in the third factor.

Table 5 shows significant principal components (H) and communalities (h^2) for female children aged 13–14 years. The four principal components isolated explained 63.64% of overall variability of the variables applied. The first principal component explained 31.87% of this variability, indicating that motor functioning in female children of this age is predominated by the integration of coordination, psychomotor speed and explosive strength, which is associated with cognitive ability. However, in order to define the first and other factors as clearly as possible, the principal components were transformed into promax solution and the factors thus isolated were interpreted on the basis of their complexes, structure and inter-correlations (Tables 6 and 7).

TABLE 5
PRINCIPAL COMPONENTS IN GIRLS AGED 13–14 YEARS

Variable	H1	H2	H3	H4	h^2
Steps laterally	–0.77	–0.05	0.13	0.02	0.61
Obstacle course backwards	–0.63	0.33	–0.44	–0.04	0.72
Board balance	0.30	0.62	–0.10	0.32	0.59
Seated straddle stretch	0.58	–0.07	0.67	0.12	0.82
Arm plate tapping	0.62	0.31	0.11	–0.14	0.52
One-foot tapping	0.71	–0.12	–0.08	–0.34	0.64
Standing broad jump	0.70	0.08	0.04	–0.40	0.66
20-m dash	–0.47	–0.23	0.45	0.21	0.53
Medicine ball throw from supine position	0.42	–0.05	–0.19	0.70	0.72
Crossed-arm sit-ups	0.58	–0.34	–0.15	0.39	0.63
Bent-arm hang	0.08	0.77	0.22	0.11	0.66
Raven's Progressive Matrices	0.48	–0.19	–0.46	–0.01	0.48
Eigen value	3.82	1.43	1.23	1.13	
% of Variance (total=63.642)	31.87	11.97	10.31	9.47	

TABLE 6
PATTERN AND STRUCUTRE MATRICES IN GIRLS AGED 13–14 YEARS

Variable	Pattern matrix				Structure matrix			
	1	2	3	4	1	2	3	4
Steps laterally	–0.59	–0.13	–0.21	–0.10	–0.74	–0.41	–0.45	–0.16
Obstacle course backwards	–0.07	–0.76	–0.15	0.17	–0.41	–0.80	–0.30	0.12
Board balance	0.10	–0.11	0.27	0.70	0.23	0.02	0.27	0.70
Seated straddle stretch	–0.10	0.91	0.07	0.12	0.29	0.89	0.18	0.17
Arm plate tapping	0.50	0.24	–0.08	0.32	0.59	0.44	0.12	0.39
One-foot tapping	0.74	0.16	–0.07	–0.16	0.76	0.43	0.22	–0.08
Standing broad jump	0.75	0.22	–0.23	0.02	0.76	0.48	0.07	0.12
20-m dash	–0.76	0.35	–0.01	–0.13	–0.64	0.04	–0.23	–0.18
Medicine ball throw from supine position	–0.16	0.08	0.86	0.19	0.20	0.17	0.81	0.16
Crossed-arm sit-ups	0.10	0.20	0.66	–0.15	0.41	0.34	0.74	–0.14
Bent-arm hang	–0.03	0.06	–0.12	0.79	0.01	0.08	–0.15	0.80
Raven's Progressive Matrices	0.54	–0.22	0.31	–0.19	0.55	0.02	0.48	–0.16

TABLE 7
FACTOR CORRELATION MATRIX IN GIRLS AGED 13–14 YEARS

Factor	1	2	3
1. General motor efficiency			
2. Regulation of muscle tone and body coordination	0.40		
3. Regulation of muscle explosive strength of upper extremities and trunk	0.36	0.16	
4. Regulation of muscle endurance and synergistic regulation	0.10	0.07	–0.03

The variables assessing explosive strength (sprint and jump type), the variables assessing the speed of frequency of lower extremity movements, the variable assessing agility/coordination and the variable assessing cognitive functioning elicited significant projections upon the first promax factor (PATTERN MATRIX) (Table 6). This factor defines general motor efficiency of pubertal girls, which is underlain by the complex integrating explosive strength of lower extremities, psychomotor speed, agility/coordination and general cognitive ability. The first factor is underlain by the combined action of subcortical regulation of movement and cognitive functioning, as also indicated by the structure of this factor in the structure matrix. This factor is named the general motor efficiency.

The second promax factor is predominantly defined by the following two variables: Seated straddle stretch (flexibility) and Obstacle course backwards (coordination), and is underlain by cortical regulation of muscle tone. This factor is named the regulation of muscle tone and body coordination.

The third promax factor is predominantly defined by the variable assessing explosive strength of throwing type (Medicine ball throw from supine position) and the variable of repetitive strength of the trunk (Crossed-arm sit-ups), with integration of the explosive strength of upper extremities and basic strength of the trunk to achieve maximal force on throwing (medicine ball, ball, shot, javelin, etc.). Such integration of motor abilities is cognitively saturated to a certain extent, as also indicated by the projections of variables in the structure matrix. This factor is named the regulation of muscle explosive strength of upper extremities and trunk.

The fourth promax factor (PATTERN MATRIX) is predominantly defined by the variable assessing static strength of upper extremities and/or muscle strength (Bent-arm hang) and the variable assessing equilibrium, which is underlain by the mechanism of synergistic regulation (Board balance). This implies integration of the mechanism responsible for muscle endurance and mechanism responsible for synergistic regulation of movements, aiming at optimal energy consumption on fixation, i.e. maintaining the position of particular body parts (e.g., endurance in rhythmic gymnastics as well as in maintaining ideal position of body parts, i.e. angles between body parts in throwing events). This factor is named the regulation of muscle endurance and synergistic regulation.

Inter-correlations among factors (Table 7) show that motor functioning in female children aged 13–14 years can generally be reduced to functions of the following three mechanisms: the mechanism responsible for the integration of force, speed and agility, which is significantly saturated by cognitive function (at the cortical level); the mechanism of responsible for the integration of muscle tone and whole body coordination (at the cortical level); and the mechanism responsible for the regulation of the muscle explosive strength of upper extremities and trunk.

Discussion

Study results on the statistically significant differences in motor variables and the variable assessing cognitive functioning in favor of the older age group (Table 1) point to strongly pronounced development of flexibility, agility, psychomotor speed, explosive strength of throwing type and repetitive strength of the trunk, probably accompanied by the parallel development of cognitive abilities at the age of 10–14 years.

Factor analysis of motor variables and cognitive variable together was employed to determine the correlation between motor and cognitive functioning, in separate for prepubertal and pubertal girls. The structure of the motor-cognitive factor isolated in a particular group of subjects was determined by the between-group and within-group differences (variations) obtained.

The results of factor analysis revealed changes to have occurred in the cognitive-motor functioning in the 13–14 age group as compared with the 10–12 age group. Accordingly, the quantitative between-group differences in the variables of cognitive and motor abilities reflected upon their structural differences.

Comparison of the motor-cognitive factor structures between the older and younger age groups revealed the motor-cognitive functioning to switch from the cortical level to the subcortical level. Thus, the first factor responsible for general motor efficiency integrates force (explosiveness of lower extremities), speed (of lower extremities in particular) and agility into a unique motor complex, which is significantly cognitively determined. The motor-cognitive factor thus structured exerts maximal motor efficiency that is manifested in the ability of the intensity of maximal energy mobilization in terms of jumps and sprint, psychomotor speed in terms of movement speed, and agility in terms of fast changes in movement direction, which is all together determined by information processing by the central nervous system. This factor is underlain by the activity of the perceptive, successive and simultaneous processor, as well as of the superior central processor, which regulates the mode and type of information processing for efficient motor functioning. In addition, on solving the Raven's Standard Progressive Matrix test, the activity of perceptive analyzer is followed by a predominant activity of serial analyzer to solve less difficult tasks and simultaneous analyzer to solve tasks that are more difficult. The correlation of motor and cognitive functioning is explained by the presumed existence of some mechanisms that are responsible for solving simultaneously both motor and cognitive problems.

In the second factor in the older age group (girls aged 13–14 years), muscle tone regulation is influenced by the mechanism for cortical regulation of movement and occurs without the impact of cognitive function. The ability of intermuscular and intramuscular coordination and achievement of optimal muscle tone on movement performance provides the basis for efficient motor functioning in girls entering the pubertal age, characterized by certain dysregulation in the development of particular body segments. Thus, there is internal motor regulation that precedes body movement in space (depending on muscle quality and joint motility). This regulation occurs independently of cognitive functioning.

While in younger age group, the third isolated factor defined as a mechanism for regulation of the explosive muscle strength of upper extremities (accompanied by the speed of movements of lower extremities and repetitive strength of the trunk) shows low and negative correlation with cognitive factor, in the older age group the mechanism for regulation of the explosive muscle strength of upper extremities and trunk shows moderate and positive correlation with cognitive factor. Regulation of the intensity of energy mobilization of upper extremities is considerably more efficient in older girls as compared with the younger ones because its manifestation implies largely the basic strength of the trunk and it is all saturated by the mechanism of movement regulation and cognitive functioning.

In female children aged 10–14 years, cognitive functioning is significantly implicated in their motor efficiency. In younger age group (10–12 years), cognitive functioning is correlated with motor complex, which integrates muscle tone regulation and agility/coordination. In older age group (13–14 years), cognitive functioning is included in the formation of the first and third factors isolated, as follows: in the first factor for the regulation of coordination and intensity of energy mobilization of lower extremities in terms of jump, sprint and agility, and in the third factor, although to a lesser extent, for the regulation of the intensity of energy mobilization of upper extremities, with a significant contribution of the basic strength of the trunk, which gives initial impetus for throw performance (ball, shot, javelin, etc.).

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RELACIJE KOGNITIVNIH I MOTORIČKIH SPOSOBNOSTI KOD DJEVOJČICA U DOBI OD 10–14 GODINA

S A Ž E T A K

Cilj ovoga istraživanja bio je utvrditi faktore kognitivnog i motoričkog statusa kod djevojčica u dobi od 10–14 godina, kao i razvojne i/ili integracijske funkcije u odnosu na dob. U istraživanje su uključene 162 djevojčice u dobi od 10–14 godina, podijeljene u dvije skupine: 84 djevojčice u dobi od 10–12 godina (srednja dob 11,26 godina, SD 0,68) i 78 djevojčice u dobi od 13–14 godina (srednja dob 13,52 godine, SD 0,63). Utvrđena je statistički značajna razlika između dviju skupina ispitanica u cjelokupnom sustavu varijabla (MANOVA) i razine značajnosti za svaku varijablu (ANOVA). Starija skupina ispitanica imala je značajno bolje rezultate od mlađe skupine u motoričkim testovima za procjenu fleksibilnosti, agilnosti, psihomotorne brzine, eksplozivne snage tipa bacanja i repetitivne snage trupa, a usporedno s tim i u testu za procjenu kognitivnog funkcioniranja. Za utvrđivanje kvalitativnih razlika između djevojčica različite dobi (predpubertetske i pubertetske dobi) matrica interkorelacija varijabli je faktorizirana postupkom glavnih komponenata koje su potom transformirane u promax soluciju. Rezultati su pokazali kako kognitivno funkcioniranje značajno sudjeluje u motoričkoj efikasnosti djevojčica u dobi od 10 do 14 godina. Kod mlađe skupine djevojčica (10–12 godina) kognitivno funkcioniranje je povezano s motoričkim sklopom koji integrira regulaciju mišićnog tonusa i agilnost/koordinaciju. Kod starije skupine djevojčica (13–14 godina) kognitivno funkcioniranje sudjeluje u formiranju prvog i trećeg izoliranog faktora: u prvom za regulaciju koordinacije i intenziteta mobilizacije energije donjih ekstremiteta (generalna motorička efikasnost) i u trećem, iako u manjoj mjeri, za regulaciju intenziteta mobilizacije energije gornjih ekstremiteta i snage trupa.