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Inter-individual Differences in Children's Kinematic Patterns of Running and Their Relationship with Body Mass Index

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A B S T R A C T

The goal of this research was to perform a kinematic analysis of the motor structure of running in children of an early and preschool age in order to determine inter-individual differences and the connection with the body mass index. The sample of participants consisted of 174 children from the Rijeka Kindergarten. The motor patterns of children's running were recorded with a video camera, and the videos were analysed in the Kinovea 0.9.5 software system. For all variables, the association was tested with Pearson's correlation coefficient, while the t-test for an independent sample and reference constant testing was used to test inter-individual differences. Interindividual differences in the kinematic parameters of children's running indicate significant heterogeneity in the performance of motor tasks. Excessive body mass in children significantly affects the prevention of their complete motor development and realization of motor potential, especially when performing more complex motor structures of running.

Key words: *motor structure, preschool age, nutritional status, kinematic analysis, body composition*

Introduction

For children of an early and preschool age running is an excellent cardiovascular activity that contributes to the health of the circulatory and respiratory systems, i.e., improves their fitness and endurance. The emergence of motor patterns of running represents one of the main milestones in the gross motor development of a child[1] and is one of the most common physical activities of preschool children[2]. As a rule, it appears during the second year of life, when children develop leg strength, balance and coordination at a satisfactory level[3]. Running is one of the first two upright movements mastered in the process of human development. On the one hand, this development depends on the degree of neuromuscular development, and on the other hand, it is influenced by the experience of movement[4].

Although previous research particularly emphasizes the comprehensive motor development of children and its connection with body mass index (BMI) and overall health[5]. there are few studies that investigate specific biomechanical analyses of running in the context of BMI among children in early and preschool age. Children with excess body weight are significantly more prone to deviate from proper movement patterns when participating in motor activities[6,7]. Children with excessive body mass have a significant problem with motor coordination, which disrupts proper movement patterns and can lead to significant locomotor injuries[8,9]. Research focused on the biomechanical aspects of running in children of an early and preschool age indicates that their motor patterns during running significantly improve with chronological age[10,11].

Studying these patterns through kinematic analysis provides better insight into how nutritional status affects motor performance. Kinematic analysis is a technique that precisely measures and describes body movement, including the speed, direction, and amplitude of individual joint movements during motion[12]. This method utilizes advanced technologies, such as high-performance cameras and body markers, to capture motor performance, which is then quantitatively analyzed using computer programs. For examining interindividual differences in running patterns, kinematic analysis is the most suitable, as it allows for the precise detection of significant variations in move-

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ment biomechanics that are not easily observable to the naked eye[13]. In the context of childhood overweight, deviations primarily relate to biomechanical changes that affect running kinematics, including reduced postural stability[14], increased joint loading[15] and decreased bilateral coordination, balance, and running speed[15]. These deviations are relevant as they may increase the risk of injury and hinder the development of proper motor patterns, potentially leading to long-term consequences for physical health and motor abilities.

The role of motor skills in promoting the health and complete motor development of children is invaluable, and is especially evident in the aspects of physical fitness, psychological well-being and social interaction[16]. Precisely because of this, the aforementioned findings of scientific research emphasize the importance of further consideration of differences in running patterns when designing appropriate physical activity programs and interventions for children.

Although this research focuses on the relationship between BMI and running kinematic patterns, it is important to recognize that other factors are crucial for a comprehensive understanding of children's motor development. By considering factors such as genetic predispositions, neuromuscular development, socioeconomic status, level of physical activity, nutrition, and psychosocial factors[17,18], a broader context can be provided for interpreting the results. This enables more precise recommendations for interventions that should address not only issues related to body weight but also other factors influencing motor development.

The goal of this research is to perform a kinematic analysis of the motor structure of running in children of an early and preschool age in order to determine interindividual differences and their connection with body mass index across all categories of nutritional status.

Methods

Participants

The research was conducted with children of an early and preschool age, i.e., a total of 174 children (97 girls and 77 boys). The children attended the regular all-day program of the Rijeka Kindergarten in the Primorje-Gorski Kotar County and their average age was 71 months (min = 29, max = 85). The average children's body height was 107.95 cm, body weight 19.63 kg, and body mass index was 16.62 m/kg^2.

Sample of variables

The first set of variables refers to basic morphological characteristics: body height and body mass. Based on the measurement data of body mass and body height, the body mass index (kg/m^2) was calculated as the ratio of body mass (kg) to body height (m) squared.

Kinematic variables were obtained by processing video recordings in the Kinovea 0.9.5 program, designed for movement analysis: average step length (cm), average duration of foot contact with the ground (ms), angle in the ankle (°), knee (°) and hip joint (°), number of steps and total duration of the task (ms).

Research protocol description

The research was conducted in accordance with the Code of Ethics for children and was approved by the Faculty of Teacher Education in Rijeka and the Council of Educators of the Rijeka Kindergarten. A parents' meeting was organized where parents were given all the necessary information about the research and filming of the children. At the same meeting, consents to participate in the research were collected. The task was to perform three motor tasks from the domain of mastering space – running. The performance of the tasks was recorded with two video cameras (side and frontal).

The first motor task was to run forward for five meters. The second motor task was running backwards on the same field of five meters in length. In the third task, i.e., slalom running, cones were placed on the marked field at a distance of 1 m, which the children had to run around. The step length was calculated from the point where one foot makes contact with the ground to the point of contact of the other foot (toes-to-toes) with the ground. The beginning of the duration of the contact of the foot with the ground was marked by the moment of the first contact of the foot with the ground, and the end was marked by the moment of the last contact of the foot with the ground. The angles were measured at the moment of maximum cushioning in the knee joint during contact of the left foot with the ground. The number of steps and the total duration of the task were measured from the starting line to the final length of five meters.

Statistical data processing

The data were analysed in the Statistica 14.0.1.25 program. Basic descriptive parameters, namely the arithmetic mean and standard deviation, were calculated for all variables. The normality of the distribution of results was tested using the Kolmogorov-Smirnov (K–S) test, and it was found that none of the variables significantly deviated from normal distribution (Table 1). The association was tested with the Pearson correlation coefficient, while the t-test for an independent sample was used to test inter-individual differences, i.e., to test the reference constant. All data are presented in the form of tables, while statistical significance was tested at the level of $p<0.05$ %.

Results

The average values and deviations of the variables that describe the executed motor patterns during running (Table 1) indicate that children running forward had on average the longest step, the shortest duration and the smallest angles in the ankle, knee and hip. It can be said that this is the most natural task for them when it comes to running, and all the mentioned parameters indicate a relatively high-quality motor structure in which children feel safe. Contrary to the above, when running backwards, children averagely had the shortest step, the longest duration and the largest angles in the joints of the ankles, knees and hips. It is clear that running backwards is unnatural and the children approached this task with the greatest amount of caution.

Furthermore, the analysis showed (Table 1) that children in all three running tasks deviated statistically significantly (p=0.00) from the overall average in the kinematic variables that describe the mentioned motor patterns. We can say that there is no tendency to a certain pattern of movement, but each child performs it significantly differently than the average.

Table 2 shows the descriptive parameters of the children's morphological variables. It can be seen that children fall into the category of normal body weight on average. However, there are individuals who, according to their values, fall into the category of malnutrition and those who fall into the category of overweight and obesity.

TABLE 2
DESCRIPTIVE PARAMETERS OF CHILDREN'S MORPHOLOGICAL VARIABLES

Body height (cm)	Body mass (kg)	BMI
103.83 ± 11.69	18.81 ± 3.72	17.49 ± 2.33

The body mass index has a statistically significant effect on certain kinematic variables that define the motor patterns of running in children (Table 3). It can be seen that children with a higher body mass index have significantly shorter steps of longer duration in backward running and slalom running, i.e., they need significantly more total time to perform the mentioned tasks. When running forward, there is no statistically significant association with body mass index.

Discussion

Children spend most of their time playing games that often involve running[2]. The kinematic analysis of straight running as a natural form of children's movement indicates the smallest angles in the ankle, knee and hip joints

TABLE 1
DESCRIPTIVE PARAMETERS AND INTER-INDIVIDUAL DIFFERENCES IN THE KINEMATIC VARIABLES DEFINING CHILDREN'S MOTOR PATTERNS OF RUNNING

Motor pattern	Variables (N=174)	M ± SD	Std.Err.	Reference Constant	t-value	df	p	K-S p
Forward running	SL	62.15 ± 18.25	4.30	0.00	14.44	173	0.00*	0.20
	DFC	214.72 ± 30.49	7.39	0.00	29.03	173	0.00*	0.20
	KA	107.01 ± 25.18	6.10	0.00	17.52	173	0.00*	0.20
	HJA	109.54 ± 16.75	4.06	0.00	26.95	173	0.00*	0.20
	AA	84.90 ± 10.44	2.53	0.00	33.50	173	0.00*	0.20
	TD	5720.88 ± 2345.45	240.85	0.00	10.05	173	0.00*	0,20
Backward running	SL	31.90 ± 11.43	2.69	0.00	11.83	173	0.00*	0.20
	DFC	366.64 ± 145.32	34.25	0.00	10.70	173	0.00*	0.20
	KA	130.83 ± 13.24	3.12	0.00	41.92	173	0.00*	0.20
	HJA	157.07 ± 17.663	4.16	0.00	37.72	173	0.00*	0.10
	AA	88.74 ± 14.26	3.36	0.00	26.39	173	0.00*	0.15
	TD	6734.42 ± 769.26	568.85	0.00	10.05	173	0.00*	0.20
Slalom running	SL	51.72 ± 19.25	4.15	0.00	13.41	173	0.00*	0.20
	DFC	261.80 ± 38.51	14.55	0.00	17.98	173	0.00*	0.20
	KA	144.74 ± 13.21	4.99	0.00	28.97	173	0.00*	0.20
	HJA	153.44 ± 8,97	3.39	0.00	45.23	173	0.00*	0.20
	AA	83.32 ± 7.71	2.91	0.00	28.59	173	0.00*	0.20
	TD	6125 ± 3578	290.75	0.00	23.16	173	0.00*	0.20

Legend: SL - Step length; DFC - Duration of the foot contact; KA - Knee angle; HJA - Hip joint angle; AA - Ankle angle; TD - Total duration; M – mean; SD – standard deviation; Std.Err – standard error; df – degrees of freedom; K-S - Kolmogorov-Smirnov (K-S) test

TABLE 3
CORRELATION BETWEEN THE BODY MASS INDEX AND THE VARIABLES DEFINING MOTOR PATTERNS OF RUNNING

Motor pattern	Step length (cm)	Duration of the foot contact (ms)	Knee angle (°)	Hip angle (°)	Ankle angle (°)	Total duration (ms)
Forward running	–0.31	0.31	0.11	0.18	–0.19	0.14
Backward running	–0.68*	0.75*	–0.39	–0.18	0.30	0.65*
Slalom running	–0.58*	0.61*	–0.04	–0.21	–0.40	0.78*

and the longest step of the shortest duration. Running in a straight line is the least motorically demanding since the child develops such a movement when learning to walk, and the connection of the muscle system is developed in the same muscle groups that ensure economy when running. By developing sensory contacts with the surface, children develop the locomotor system as a prerequisite for the development of later proper walking and running[19]. The complexity of the motor task influenced a further increase in the angles in the mentioned joints and a shorter step of longer duration. Less demanding motor task is reflected in the development and duration of individual running phases, which gradually develop in accordance with the development of the entire organism. Determining the phases of running, i.e., the flight phase, is simpler and more harmonious with the increase in chronological age[20,21]. In addition to the demandingness of the motor task, differences in kinematic indicators can also be the result of functional differences[22]. It can be said that the differentiation of forward, backward and slalom running in a straight line is mainly observed in the type of muscle contraction, rate of development of muscle force, intermuscular coordination and similar parameters.

Running through play not only satisfies children's need for movement but also supports their physical development and contributes to their cognitive and emotional growth[23]. In terms of kinematic characteristics, children's running is distinct, with smaller joint angles at the ankle, knee, and hip, which is associated with natural biomechanical adaptations[23]. Children go through stages of motor development that include increasing muscle strength and coordination, and straight-line running serves as a foundation for the development of more complex movements, such as changing direction or accelerating[24].

Sensorimotor interactions with the surface and the development of balance are crucial for proper walking and running[25]. The process of adapting muscle activity depends on afferent information from the muscle-tendon systems, which develop and become more efficient over time[26]. Learning sensorimotor integration allows children to optimize movements, reducing unnecessary energy expenditure during activities such as running. As children grow, they gradually transition from simpler to more complex forms of running, where movement control and efficiency take precedence, requiring further development of muscle coordination and strength[27].

During the running tasks, kinematic analysis determined that there is no tendency to a certain pattern of movement, but that each child performs them significantly differently than the average. Contemporary research is usually focused on describing the mechanics of running which is behind the developmental process of running[28,29]. Furthermore, it is important to determine the factors responsible for the large variability in running patterns and the changes that occur in these patterns during growth and maturation[30]. Knowing the factors and their influences could contribute to a better understanding of the great variability obtained through this research. The factors that can affect the running pattern are divided into three categories: organismic factors (physical, physiological, morphological and psychological factors), environmental factors (shoes, type of surface, incline), task-related factors (running modality, speed) and their mutual interactions[31]. The surface and footwear directly influence the kinetics and kinematics of running. The type of surface, for example, affects impact absorption and energy release with each step. Running on different surfaces requires a different pattern of muscle activation and alters running biomechanics[31]. Hard surfaces result in greater acceleration and higher impact forces, which can lead to an increased risk of injury; therefore, a combination of hard and soft surfaces is recommended[32]. Proportionally to the development of the muscular and locomotor system, each organism adapts to the forces that act during the activity of running, and due to individual adaptations, the performance deviates from the average movement patterns. Such adaptations of the organism are associated with the interrelationship of muscle tissue, sensory stimuli and the organism's response to external factors[33].

By developing various motor skills, children demonstrate differences in running techniques when moving forward, backward, and sideways (slalom). Each of these techniques involves specific patterns of muscle activity and types of contractions. For instance, backward running requires increased eccentric muscle contractions, while slalom running necessitates rapid changes in direction and activation of muscles responsible for stabilization and agility. In this context, intermuscular coordination plays a crucial role in adapting running styles, thereby further developing neuromuscular control. Differences in kinematic indicators of running may also result from functional characteristics, including variations in muscle strength, flexibility, and neuromuscular control[34]. Children with different levels of motor competence may exhibit distinct movement patterns, indicating individual variations in their motor development. The development of correct biomechanical patterns facilitates the transfer to improved motor performance in both sports and other activities[35,36] such as running. In conclusion, natural running in children arises from the interaction of biomechanics, motor development, and sensorimotor integration[31,37].

Children with a higher body mass index have significantly shorter steps of longer duration in backward running and slalom running, i.e., they need significantly more total time to perform the mentioned tasks. Similar results have been confirmed in the analysis of walking in early and preschool-aged children. Children with a higher BMI exhibit significantly shorter strides when walking backward and on a Swedish bench, requiring considerably more time to complete the task, with a significantly longer average duration of contact with the surface[38]. Backward running involves a different movement pattern compared to forward running, with greater activation of eccentric muscles[39], and this form of movement also has higher metabolic demands[40]. Children with higher BMI often exhibit reduced neuromuscular control and stability, making it more difficult to manage forces[41]. Increased body mass can slow the response of muscle groups responsible for stabilization, resulting in shorter steps and longer step durations[42]. Additionally, a higher BMI can alter joint biomechanics, reducing movement efficiency[43]. Tasks such as running backward are physiologically more demanding due to the increased need for neuromuscular control and coordination, and higher body mass requires more energy for movement, further straining the muscles. This situation may lead to poorer motor performance in complex tasks, as confirmed by research showing that children with higher BMI have shorter steps and slower reaction times[3]. Additionally, they have less body control and functional ability[44]. These findings highlight the need for further research to better understand the specific gait adaptations in children with higher BMI.

It has been proven that higher BMI values are associated with differences in kinematics, joint kinetics and increased vertical load during walking[45]. Children with excess body weight or obesity show slower walking speed, longer time spent in the double support phase, shorter step lengths and greater step width compared to children with optimal body weight[21,46]. Research indicates that the differences are more pronounced during running, where tibiofemoral contact forces in healthy individuals were 2–3 times higher during running compared to walking[46].

Furthermore, contemporary research shows that children with an increased BMI on average show up to 25 % higher peak vertical force and 45 % higher peak pressure on the foot during running[47]. Higher joint moments and surface reaction forces may indicate an increased risk of injury or the development of joint degeneration in children with excessive body weight[49]. It is clear that an elevated BMI significantly affects the poor quality of the performance of motor patterns and significantly prevents the complete motor development of the child.

Running through play represents one of the key elements of the natural development of motor skills in children, providing them with the opportunity to develop various motor and cognitive abilities through spontaneous activities. One important aspect of such activities is the development of spatial and temporal perception, which enables children to better understand their body in relation to their environment and to respond to changes in that environment in a timely and efficient manner. Running through play represents one of the key elements of the natural development of motor skills in children, providing them with the opportunity to develop various motor and cognitive abilities through spontaneous activities. One important aspect of such activities is the development of spatial and temporal perception, which enables children to better understand their body in relation to their environment and to respond to changes in that environment in a timely and efficient manner. These abilities directly influence a child's capacity to coordinate movements and plan actions, particularly in situations that require rapid changes in direction and pace, such as running during play.

The limitations of this research can be viewed from at least two perspectives. First, it has been established that the problem exists, but to gain insight into the broader picture, it is necessary to use sophisticated technological instruments in future studies. Second, these instruments will allow for measuring children in situational conditions, utilizing children's motor patterns in a real physical environment. This is particularly important for identifying the characteristics upon which preventive kinesiology interventions for children will be based.

Conclusion

The body mass index has a statistically significant effect on certain kinematic variables that define the motor patterns of running in children. Children with a higher body mass index have significantly shorter steps of longer duration in backward running and slalom running, i.e., they need significantly more total time to perform the mentioned tasks. Excessive body mass in children significantly affects the prevention of their complete motor development and realization of motor potential, especially when performing more complex motor structures of running. In all three motor tasks of running, each child significantly deviates from the average in the kinematic variables that describe the mentioned motor patterns of running. Running, as one of the basic forms of children's movement, needs to be improved in order to make the motor patterns more homogeneous.

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INTERINDIVIDUALNE RAZLIKE U KINEMATIČKIM OBRASCIMA TRČANJA KOD DJECE I POVEZANOST S INDEKSOM TJELESNE MASE

S A Ž E T A K

Cilj ovog istraživanja bio je izvršiti kinematičku analizu motoričke strukture trčanja djece rane i predškolske dobi u svrhu utvrđivanja interindividualnih razlika i povezanosti s indeksom tjelesne mase. Uzorak sudionika činilo je 174 djece iz Dječjeg vrtića Rijeka. Motorički obrasci trčanja djece snimani su videokamerom, a videozapisi analizirani u programskom sustavu Kinovea 0.9.5. Za sve su varijable, povezanost je testirana Pearsonovim koeficijentom korelacije, dok je za testiranje interindividualnih razlika primijenjen je t – test za samostalni uzorak i testiranje referentne konstante. Interindividualne razlike u kinematičkim parametrima trčanja djece ukazuju na značajnu heterogenost u izvedbi motoričkih zadataka. Prekomjerna tjelesna masa kod djece značajno utječe na sprječavanje njihovog cjelovitog motoričkog razvoja i ostvarenje motoričkih potencijala, posebno pri izvedbi složenijih motoričkih struktura trčanja.