THE IMPACT OF A PROGRAMMED KINESIOLOGICAL TREATMENT ON NEUROMUSCULAR RESPONSES IN CHILDREN

[1]Nevena Stupar,
[1]Dalibor Stević,
[2]Slaviša Vujanović,
[1]Nebojša Mitrović,
[2]Marijana Rikić.
[1]Faculty of Education, Bijeljina, University of East Sarajevo, BiH,
[2]Public Institution "Cika Jova Zmaj" Kindergarten Bijeljina, BiH.

ISSN 1840-152X
UDK: 796.015:612.741-053.5
https://doi.org/10.7251/SIZ2501049S
https://sportizdravlje.ues.rs.ba/index.php/sah
https://doisrpska.nub.rs/index.php/SIZ

ORIGINAL SCIENTIFIC ARTICLE

Abstract: It is known that a decrease in neuromuscular reaction speed affects executive function, leading to poorer planning, goal setting, decision-making, attention, or reading, and that young children with slow reaction speeds are more likely to have academic difficulties and exhibit symptoms of attention deficit and hyperactivity.

The sample consisted of 110 fifth-grade students from the elementary schools "Knez Ivo od Semberije" and "Sveti Sava" in Bijeljina, aged 10 ± 6 months, both male and female. The first group included 59 students (33 boys and 26 girls) who participated in a programmed kinesiology treatment aimed at improving muscle reaction speed, while the second control group consisted of 51 students (29 boys and 22 girls) who attended physical education classes according to the curriculum set by the Ministry of Education and Culture of the Republic of Srpska, with a weekly fund of 3 classes. All participants were fifth graders from the mentioned schools in Bijeljina. The following exercises were used to assess muscle reaction speed: Lunge, Isometric single-leg squat, Squat, Isometric squat.

Electromyography is an indirect diagnostic procedure for assessing electrical activity generated in muscles by nerve impulses that create an action potential in the membrane of the muscle fiber, either at rest or during activation.

The results show that in most analyzed variables, no statistically significant differences were observed. In the variable sEmg Lunge, a statistically significant difference was observed at $t = -2.42$; $p = 0.04$. To improve neuromuscular reaction speed, the exercise program must focus on the neuromuscular system. To improve reaction speed, a child must not carry significant amounts of subcutaneous fat.

Keywords: Neuromuscular reaction speed, children, fifth grade

INTRODUCTION

Movement is a fundamental part of life. It is well known that human movement offers numerous benefits, both physical and psychological. It promotes healthy joints, strong bones, physical strength, good circulation, coordination, and reflex responsiveness, as well as improved learning and concentration skills. Human movement also represents the freedom of self-expression through the body, as well as the safety and value of survival. For children, movement is especially important as it helps them grow. It serves as a method of establishing contact and communication, and can also enhance memory, perception, language, attention, emotions, and even decision-making (Barnett, Hnatiuk, Salmon, & Hesketh, 2019). During the preschool years, rapid changes occur in brain development, with the brain reaching 95% of its adult volume by the age of six (Giedd & Rapoport, 2010). One of the key cognitive abilities during early childhood is "processing speed" (Fry & Hale, 1996). Reaction time is the ability to complete basic cognitive functions such as object identification (Fry & Hale, 2000). It has been shown that this ability fully mediates the relationship between age and inhibitory control and partially mediates the relationship with working memory in middle childhood (McAuley & White, 2011). Span, Ridderinkhof, and van der Molen (2004) also found that after controlling for processing speed and reaction time, there was no difference in executive function between adults and children. It is well known that a reduction in reaction time negatively impacts executive function, leading to poorer planning, goal setting, decision-making, attention, or reading abilities (Kail & Salthouse, 1994). Young children with slow reaction times are more likely to face academic difficulties (Bull & Johnston, 1997) and show symptoms of decreased attention and hyperactivity (Verret, Guay, Berthiaume, Gardiner, & Béliveau, 2012). A growing body of evidence shows that physical fitness improves cognitive abilities during childhood (Khan & Hillman, 2014; Singh et al., 2019). During sustained muscle contraction, the depolarization and propagation of action potentials in muscle fibers are altered. These modifications produce time-dependent changes in the resulting surface electromyographic (EMG) signal. It is well known, for example, that the EMG signal undergoes a shift of its power spectrum toward lower frequencies, as well as a change in its waveform during constant-force isometric contraction (Merletti, Rainoldi, & Farina, 2005). Neuromuscular training, as a training program, includes general (e.g., fundamental movements) and specific (e.g., sport-specific movements) strength and conditioning activities such as resistance, dynamic stability, balance, core strength, plyometric exercises, and agility drills. The goal is to improve health- and skill-related components of physical fitness and prevent injuries. According to this theory, agility, balance, plyometrics, strength training, and stability training are subsets of neuromuscular training (Myer et al., 2011). Research by prominent scientists in this field indicates that neuromuscular training has positive effects on motor skills, injury prevention, and muscular fitness in children and adolescents (Delitto et al., 1989; Eriksson et al., 1981; Granacher et al., 2016; Lake, 1992; Maffiuletti et al., 2000, 2002). The aim of this paper was to analyze the effects of a programmed kinesiological treatment on neuromuscular responses in fifth-grade elementary school children. The programmed kinesiological treatment is expected to have a positive impact on neuromuscular responses in children.

METHODS

Participants

The sample consisted of 110 fifth-grade students from the elementary schools "Knez Ivo od Semberije" and "Sveti Sava" in Bijeljina, aged 10 ± 6 months, of both sexes. The first group included 59 students (33 boys and 26 girls) who participated in a programmed kinesiological treatment aimed at improving muscle reaction speed. The second, control group consisted of 51 students (29 boys and 22 girls) who attended regular physical education classes according to the official curriculum of the Ministry of Education and Culture of the Republic of Srpska, with a weekly load of three classes. All participants were fifth-grade students from the aforementioned elementary schools in Bijeljina. The research was conducted in accordance with the Declaration of Helsinki for biomedical research (2013), which stipulates that parents must provide written consent for the testing of each child.

The following exercises were used to assess muscle reaction speed:

I EMG Muscle Reaction Speed in Healthy Children

1) Lunge
2) Isometric Single-Leg Squat
3) Squat
4) Isometric Squat

Electromyography (EMG) is an indirect diagnostic procedure used to assess the electrical activity produced in muscles by a nerve impulse that generates an action potential in the myocyte membrane, either at rest or during the activation phase. In general, EMG can be classified according to the testing protocol applied to the individual being evaluated (Fernandez-Lazaro et al., 2020):

a) Resting EMG (assesses the electrical activity of the basal muscle);
b) Voluntary EMG (evaluates the muscle response following an action); and
c) Evoked Potential EMG (assesses motor units).

EMG is a type of recording equipment composed of several components: adhesive electrodes, an amplifier, and a recording system. There are two types of electrodes: internal or needle electrodes (used for deep EMG or integrated EMG – iEMG) and surface electrodes, which were used in our study (kinesiological or surface EMG – sEMG). The electrodes emit and collect the EMG signal, which is then sent to a computer that detects the potential difference and eliminates interference. The signal is then quantified using a recording system that expresses the signal relative to a previously obtained reference value. There are two basic signal amplification methods: monopolar and bipolar configuration. Furthermore, there are various types of recording systems that collect data, such as graphical records, oscilloscope recordings, permanent paper records, or permanent photographic records. Electromyography measures the muscle's response, or electrical activity, in reaction to nerve stimulation of the muscle. The electrical activity picked up by the electrodes is displayed on an oscilloscope—a monitor that shows electrical activity in waveforms. EMG records the electrical activity of muscles during rest, mild contraction, and forceful contraction. Normally, muscle tissue does not produce electrical signals at rest. When the electrode is inserted, a brief burst of activity may be seen on the oscilloscope, but after that, there should be no signal present (Johns Hopkins Medicine, 2023).

After the electrode was placed, the participant was asked to perform the following activities:

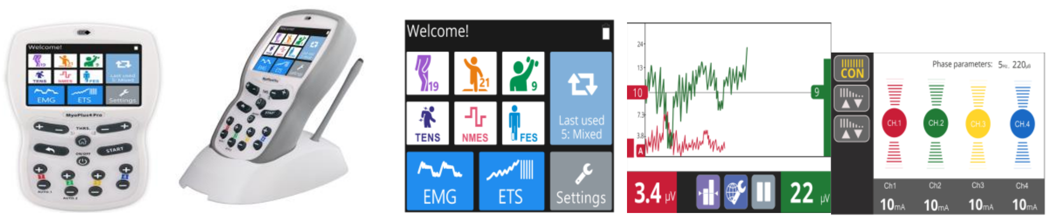
1) Lunge
2) Isometric Single-Leg Squat
3) Squat
4) Isometric Squat

The results were recorded using the non-invasive EMG device: NeuroTrac® MyoPlus 4 Pro.

The action potential generated on the oscilloscope provides information about the muscle's ability to respond to nerve stimulation. As the muscle contracts more strongly, more muscle fibers are activated, producing action potentials.

EMG is a low-risk procedure, and complications are rare. Every body movement a person makes, from lifting a leg to nodding the head, involves complex communication between the central nervous system (brain and spinal cord), nerves, and muscles. To produce movement, motor nerves send electrical signals to the muscles. EMG measures the muscle's response to electrical activity and how much electrical activity is generated by muscle contraction.

NeuroTrac® MyoPlus 4 Pro



Characteristics of the EMG device used:

EMG

1. Two-channel EMG
2. EMG range: 0.2 to 2000 μV RMS (continuous)
3. Sensitivity: 0.1 μV RMS
4. Accuracy: 4% of reading ±0.3 μV at 200 Hz
5. Selectable bandwidth filter – 3 dB passband,
6. Wide: 18 Hz ± 4 Hz to 370 Hz ± 10% – Reading below 235 microvolts 10 Hz ± 3 Hz to 370 Hz ± 10% – Reading above 235 microvolts
7. Narrow: 100 Hz ± 5% to 370 Hz ± 10%
8. Notch filter: 50 Hz (Canada 60 Hz) – 33 dB (0.1% accuracy)
9. Common mode rejection ratio: minimum 130 dB @ 50 Hz
10. Work/rest periods: 2–99 seconds

11. Number of attempts: 1–99

STIM (neuromuscular stimulation)

1. 4-channel stimulator
2. Amplitude: 0–90 mA at 500 ohm load – actual mA tends to be lower than indicated due to electrode impedance: at 1000 ohm load (poor electrode condition) max limited to 75 mA, at 1500 ohm load max limited to 50 mA.
3. Type: Constant current, maximum output voltage 70 Volts +5 / -10 Volts
4. Waveform: Symmetrical, rectangular, biphasic with net zero DC current
5. Pulse width selection: 50–450 μS (±2% accuracy)
6. Pulse rate selection: 2–100 Hz (±2% accuracy)
7. Work/rest periods: 2–99 seconds
8. Time: 1–99 minutes
9. Ramp time: 0.1–9.9 seconds
10. Pre-set and programmable treatment programs
11. Automatic output shutdown with open electrode detection above 0.5 mA
12. Battery: 4 x 1.5 V AA. Low battery indicator at 4.2–4.4 volts ±0.2 volts, automatic shutdown when voltage falls below low battery indicator. Replace batteries immediately! Device automatically shuts off when unused (energy saving): e.g., in settings mode if no button is pressed for more than 1 minute, or in stimulation mode (start screen) when all channels are at 0 mA.
13. Expected average battery life [standard 800 mAh, alkaline]:
14. a. MioPlus2: 12–16 hours in STIM mode, 25 hours in EMG mode.
15. b. MioPlus4: 8–16 hours in STIM mode, 25 hours in EMG mode.
16. Environmental conditions for use: +5 to +40 degrees Celsius, 15–90% humidity
17. Environmental conditions for storage and transport: -25 to +70 degrees Celsius, 15–90% humidity
18. Physical dimensions: Length 150 mm, width 89 mm, depth 35 mm
19. Weight: MioPlus 4 and MioPlus 2 device: 0.16 kg (without batteries).

Experimental program

The experimental program, based on exercises to improve muscle reaction speed in the experimental group, was conducted over eight weeks, three times per week, from December 2023 to February 2024.

Table 1. Experimental program

Week	Goal of the training	Exercises by sessions (3x weekly)	Duration / Load	Notes / Progression
1–2 Introductory Phase	Neuromuscular System Activation, Coordination, Technique	Dynamic warm-up Basic stabilization Reaction games: visual signals (start/stop),	30 min per session	Focus on technique and movement control. Without load..

Week	Goal of the training	Exercises by sessions (3x weekly)	Duration / Load	Notes / Progression
		catching the ball Mini-jumps in place Balance exercises: single-leg stance with closed eyes		
3–4 Development of Strength and Reaction	Reaction Speed and Explosive Contraction	Low-intensity plyometrics: Forward jump Lateral jump (or Side jump) Rapid changes of direction (or Quick changes of direction) Reaction drills with sound or color Stabilization exercises: plank with shoulder tap	30 min per session	Progression in speed of execution is introduced; short work intervals (5–10 sec), rest 30–40 sec.
5–6 Explosive Phase	Development of Explosive Strength and Synchronization	Medium-intensity plyometrics: Box jump (30–40 cm) Lateral bounds Squat jump Sprint starts from various positions (kneeling, lying down) Reaction sprints (reaction to voice/sound or light) Rapid medicine ball drills (2–3 kg): throwing against a wall, squat to press (or squat to overhead lift)	30 min per session	Progression: more repetitions (3–5 per set), higher intensity, shorter rest periods.
7–8 Integrative and Functional Phase	Connecting Motor Skills into Specific Movements	Combined drills (jump + sprint, sprint + change of direction) Team reaction games Complex tasks with visual stimuli Core stabilization with dynamic load (medicine ball, elastic bands / resistance bands)	30 min per session	Integration of all abilities; focus on response speed and movement control under fatigue.

The study was carried out on a sample of 110 participants, divided into two subsamples. One subsample, the experimental group, consisted of students from the primary school "Knez Ivo od Semberije" in Bijeljina, while the other subsample, representing the control group, consisted of students from the primary school "Sveti Sava" in Bijeljina. The students were given oral and visual demonstrations of the exercises and how to perform them to ensure feedback during the kinesiology treatment.

Each session included basic components of movement preparation, work on movement biomechanics, nerve stimulation, and, finally, coordination exercises. The goals of movement preparation were to increase body temperature, active stretching, activation of the nervous system, proprioceptors, and stabilizers, improvement of kinesthetic perception, and refinement of technique by strengthening relevant motor programs on a daily basis before the main part of the session. The preparatory part of the session was conducted with the aim of maximizing the active range of motion necessary for unhindered movement.

These exercises involved proper body positioning, core stability, balance, coordination, and range of motion through all planes of movement. Movement preparation followed a specific sequence from low-intensity activities that raise body temperature to more intense dynamic movements. The introductory exercises began with basic active movements such as low-intensity running, side-stepping, karaoke exercises, waves and turns, and light games that enhanced kinesthetic perception and grip exercises. The preparatory mobility exercises aimed to mobilize and strengthen specific parts of the body with bending, extending, and rotating movements. These exercises actively facilitated body movement by gradually elongating and preparing muscles for more intense dynamic flexibility.

Examples of some exercises used include lunges and side lunges.

- Lying on the back or stomach
- Standing (trunk rotation and diagonal movement patterns in standing position)
- Movement (forward, backward, and sideways walking on hands, lunges, jumping, and crawling under obstacles)

Dynamic flexibility exercises included a progression from simple walking, marching, and jumping to running that started from the feet and progressed upward through the body to the head. These movements began slowly with small amplitudes and then transitioned into large, fast movements activating systems significant for the experimental session.

Work on movement biomechanics represented a fundamental component of each exercise. The principles on which it is based—dorsal flexion, positive angles, arm positioning, central stability, and ground reaction forces—are integral parts of every aspect of athletic performance. During the phase focused on movement biomechanics, the students were already thoroughly warmed up and prepared, allowing progression to the application of programmed tasks.

Nervous stimulation and the eccentric-concentric cycle, along with exercises emphasizing nervous system activation, were applied not only to enhance the elastic properties of muscles but also to improve motor learning and the overall understanding of the programmed activity. The selection of these exercises was primarily based on the activity's goal, as well as the level at which they were performed (beginner, intermediate, or advanced).

Basic descriptive parameters were calculated for all variables, including: minimum (MIN) and maximum measured values (MAX), arithmetic mean (AM), standard deviation (SD), skewness – a measure of distribution symmetry (SK), and kurtosis – a measure of distribution homogeneity (KUR). The normality of the distribution was tested using the Kolmogorov–Smirnov test, and differences between the first and second measurements were calculated using the paired samples *t*-test at a 95% confidence interval.

RESULTS

Table 2. Descriptive statistics of electromyographic data at the initial measurement

EMG			AS	S	MIN	MAX
RMS	E	Lunge	0,13	0,03	0,08	0,17
	K		0,11	0,03	0,07	0,16
	E	Isometric	0,14	0,04	0,10	0,22
	K	Single-Leg	0,09	0,06	0,01	0,17
	E	Squat	0,14	0,05	0,02	0,20
	K		0,16	0,05	0,08	0,21
	E	Isometric	0,15	0,03	0,11	0,19
	K	Squat	0,14	0,04	0,07	0,18
sEMG	E	Lunge	0,09	0,03	0,05	0,16
	K		0,08	0,03	0,04	0,13
	E	Isometric	0,14	0,03	0,10	0,20
	K	Single-Leg	0,08	0,05	0,01	0,15
	E	Squat	0,11	0,04	0,02	0,16
	K		0,12	0,04	0,06	0,16
	E	Isometric	0,13	0,03	0,10	0,18
	K	Squat	0,12	0,03	0,06	0,16

***Legend**: AS – Arithmetic Mean; S – Standard Deviation; MIN – Minimum recorded measurement result; MAX – Maximum recorded measurement result; EMG – Electromyography; E – Experimental Group; K – Control Group; RMS – Root Mean Square; sEMG – Surface Electromyographic Recording.*

An examination of the descriptive indicators of electromyographic data at the initial measurement for both the experimental and control groups reveals good discriminative ability in most analyzed variables for both RMS and sEMG, except for the variables Single-Leg Squat in the control group, Squat in the experimental group for RMS, and Lunge in the experimental group, Single-Leg Squat in the control group, and Squat in the experimental group for sEMG. In all other variables, it was possible to group three standard deviation values within one arithmetic mean value. Based on the range results, poorer range values were observed in most analyzed variables for both the experimental and control groups, as it was not possible to group five to six standard deviation values within one range value.

Table 3. Descriptive indicators of electromyographic data at the final measurement

EMG			AS	S	MIN	MAX
RMS	E	Lunge	0,10	0,02	0,08	0,17
	K		0,11	0,03	0,07	0,16
	E	Isometric	0,12	0,03	0,10	0,22
	K	Single-Leg	0,10	0,05	0,01	0,17
	E	Squat	0,12	0,04	0,02	0,21
	K		0,15	0,04	0,07	0,20
	E	Isometric	0,13	0,03	0,11	0,18
	K	Squat	0,15	0,03	0,06	0,17
sEMG-electromyographic	E	Lunge	0,08	0,03	0,05	0,15
	K		0,08	0,03	0,04	0,12

recording	E	Isometric	0,12	0,03	0,09	0,19
	K	Single-Leg	0,08	0,05	0,01	0,16
	E	Squat	0,10	0,04	0,03	0,18
	K		0,11	0,03	0,06	0,15
	E	Isometric	0,12	0,03	0,9	0,19
	K	Squat	0,12	0,03	0,07	0,17

Legend: *AS – Arithmetic Mean; S – Standard Deviation; MIN – Minimum recorded measurement result; MAX – Maximum recorded measurement result; EMG – Electromyography; E – Experimental Group; K – Control Group; RMS – Root Mean Square; sEMG – Surface Electromyographic Recording.*

Analysis of the basic descriptive indicators of electromyographic data at the final measurement for both the experimental and control groups reveals good discriminative ability in most of the analyzed variables for both RMS and sEMG, except in the variables of Single-Leg Squat in the control group for RMS, Lunge in both the control and experimental groups, Single-Leg Squat in the control group, and Squat in the experimental group for sEMG. In all other variables, it was possible to group three standard deviation values into a single mean result value. Observing the range results, poorer range values are noted across all analyzed variables in both the experimental and control groups, as it was not possible to group five to six standard deviation values into a single range value.

Table 4. Normality of Distribution Tested by the Kolmogorov–Smirnov Test of Electromyographic Data in the Experimental Group after Initial Measurement

EMG		KS	p	MEA
RMS	Lunge	,791	,558	,121
	Isometric Single-Leg	,788	,564	,120
	Squat	,719	,679	,112
	Isometric Squat	,412	,996	,064
sEMG-Electromyographic recording	Lunge	,635	,816	,099
	Isometric Single-Leg	,469	,980	,073
	Squat	,632	,820	,099
	Isometric Squat	,392	,998	,062

Legend: *K-S – Kolmogorov–Smirnov Z coefficient; p – level of statistical significance of the Kolmogorov–Smirnov Z coefficient; MEA – maximum absolute difference between the observed and expected distribution.*

Reviewing the results in Table 4, which shows the normality of the distribution of anthropometric variables for the experimental group after the initial measurement, tested by the Kolmogorov–Smirnov test, it is concluded that there is no statistically significant deviation of the tested distribution from normality.

Table 5. Normality of distribution tested by Kolmogorov–Smirnov test of electromyographic data for the control group after the initial measurement

EMG		KS	p	MEA
RMS	**Lunge**	,953	,324	,139
	Isometric Single-Leg	1,047	,223	,153
	Squat	,824	,506	,120
	Isometric Squat	,606	,857	,088
sEMG-Electromyographic recording	**Lunge**	,801	,543	,117
	Isometric Single-Leg	,536	,936	,082
	Squat	,870	,436	,133
	Isometric Squat	,678	,748	,103

Legend: *K-S – Kolmogorov–Smirnov Z coefficient; p – level of statistical significance of the Kolmogorov–Smirnov Z coefficient; MEA – maximum absolute difference between the observed and expected distribution.*

Analysis of the data in Table 5, which presents the normality of distribution of anthropometric variables for the control group after the initial measurement tested by the Kolmogorov–Smirnov test, concludes that there is no statistically significant deviation of the tested distribution from normality.

Table 6. Differences Between the Experimental and Control Groups at the Final Measurement

EMG		AS	S	t	p
RMS	**Lunge**	0,13 0,15	0,03 0,04	-0,88	0,35
	Isometric Single-Leg	0,14 0,15	0,05 0,03	-0,71	0,49
	Squat	0,11 0,09	0,03 0,06	1,20	0,29
	Isometric Squat	0,16 0,15	0,05 0,04	0,71	0,62
sEMG-Electromyographic recording	**Lunge**	0,09 0,14	0,03 0,03	-2,42	0,04
	Isometric Single-Leg	0,11 0,13	0,04 0,03	-1,60	0,15
	Squat	0,08	0,03	0,13	0,89

Isometric Squat	0,08 0,12 0,12	0,05 0,04 0,03	-0,65	0,59

Legend: *AS – arithmetic mean SD – standard deviation t – t-test value p – level of significance of the t-test RMS – root mean square sEMG – surface electromyographic recording*

Based on the values in Table 6, which show the differences between the experimental and control groups analyzed using the t-test for two independent groups, it can be concluded that no statistically significant differences were observed in most of the analyzed variables. Only in the variable Lunge, based on the sign of the t-test and its statistical significance, significant differences in favor of the experimental group were observed at the final measurement.

DISCUSSION

The results obtained in this study, in which no statistically significant differences in favor of the experimental group were recorded, can be viewed in the broader context of similar research that has demonstrated positive effects of neuromuscular training in children and youth (Faigenbaum et al., 2013; Lloyd et al., 2016). Differences in findings may be attributed to the shorter duration of the program (eight weeks), smaller sample size, possible uncontrolled physical activity outside the program, and lack of dietary control—all of which are factors that could potentially influence the outcomes. Additionally, initial inequalities between the groups, such as differences in biological maturity, physical fitness levels, and motivation, may have affected adaptation and the magnitude of the effect. Accordingly, it is recommended that future studies conduct longer-term interventions (at least 10–12 weeks) with a larger number of participants, control of external physical activities and nutritional habits, and inclusion of biological maturity measures as covariates. Practically, neuromuscular training programs should combine explosive and coordination exercises with clear progression and high technical execution quality in order to achieve stable and transferable adaptations in reaction speed and movement control.

To improve the speed of neuromuscular reaction, the emphasis of the exercise program must be on the neuromuscular system. Therefore, practical exercises must be scientifically supported so that muscles learn to activate faster and the central processor (brain) is enabled to learn specific movement patterns at high execution speeds. Training the nervous system ensures the memorization of motor patterns for performing complex explosive movements. Improvement in this regard is not reflected in physical adaptation caused by overload, but in neuromuscular adaptation that requires performing explosive and precise movements combined with perfect technique. This type of training increases the brain's ability to quickly engage the "machine" it controls (the human body). A program designed to develop these abilities influences an increase in the firing frequency of motor neurons, selective and maximal recruitment of fast muscle fibers, i.e., faster reaction and faster force production.

For the execution of a desired movement, complex neurophysiological synchronization is necessary to control and trigger the appropriate muscle fibers in a specific sequence. Considering that many muscles contributing to the expression of reaction speed in specific activities are relatively small (external and internal rotators, adductor and abductor muscles) and insufficiently strong for explosive contraction, only their combined action enables a child to perform the desired movement pattern and achieve the required speed.

Synchronization is below optimal when fatigue and lactate accumulation hinder performance. From a bioenergetic perspective, reaction speed improves exclusively through the phosphocreatine energy system, i.e., anaerobic training methods. However, in gameplay, explosive movements are often required when the individual is already in a state of fatigue.

CONCLUSION

To improve reaction speed, a person must not carry significant amounts of subcutaneous fat. Fat does not contribute to force production, so its presence (proportional to the amount) creates additional load that the muscles need to overcome. The focus in physical development should be on the lower extremities and the so-called speed center, i.e., the trunk muscles (abdominal muscles, lower back muscles, hip abductors and adductors, rotators, flexors and extensors of the hip, and gluteal muscles), which are responsible for producing and transferring high velocity values. Muscle hypertrophy in these regions lowers the body's center of gravity. Excessive hypertrophy of the upper body instead of the lower body raises the center of gravity, weakens dynamic balance, alters technique, and limits the expression of reaction speed at the start of movement execution (the first step) and when changing direction.

It is necessary to be careful with the exercises applied for development, as it often happens that individuals who are not well-prepared immediately move on to specific exercises for developing neuromuscular reaction speed. Future studies should consider a greater number of variables, a longer experimental training period, as well as a larger sample of subjects.

REFERENCES

Barnett, L. M., Hnatiuk, J. A., Salmon, J., & Hesketh, K. D. (2019). Modifiable factors which predict children's gross motor competence: A prospective cohort study. *International Journal of Behavioral Nutrition and Physical Activity, 16*(1), 1–11. https://doi.org/10.1186/s12966-019-0888-0

Bull, R., & Johnston, R. S. (1997). Children's arithmetical difficulties: Contributions from processing speed, item identification, and short-term memory. *Journal of Experimental Child Psychology, 65*(1), 1–24. https://doi.org/10.1006/jecp.1996.2358

Delitto, A., Brown, M., Strube, M. J., Rose, S. J., & Lehman, R. C. (1989). Electrical stimulation of quadriceps femoris in an elite weight lifter: A single subject experiment. *International Journal of Sports Medicine, 10*(3), 187–191. https://doi.org/10.1055/s-2007-1024898

Eriksson, E., Häggmark, T., Kiessling, K. H., & Karlsson, J. (1981). Effect of electrical stimulation on human skeletal muscle. *International Journal of Sports Medicine, 2*(1), 18–22. https://doi.org/10.1055/s-2008-1034578

Faigenbaum, A. D., Lloyd, R. S., & Myer, G. D. (2013). Youth resistance training: Past practices, new perspectives, and future directions. *Pediatric Exercise Science, 25*(4), 591–604. https://doi.org/10.1123/pes.25.4.591

Fernández-Lázaro, D., Fernandez-Lazaro, C. I., Mielgo-Ayuso, J., Navascués, L. J., Córdova Martínez, A., & Seco-Calvo, J. (2020). The role of selenium mineral trace element in exercise: Antioxidant defense system, muscle performance, hormone response, and athletic performance. A systematic review. *Nutrients, 12*(6), 1790. https://doi.org/10.3390/nu12061790

Fry, A. F., & Hale, S. (1996). Processing speed, working memory, and fluid intelligence: Evidence for a developmental cascade. *Psychological Science, 7*(4), 237–241. https://doi.org/10.1111/j.1467-9280.1996.tb00366.x

Fry, A. F., & Hale, S. (2000). Relationships among processing speed, working memory, and fluid intelligence in children. *Biological Psychology, 54*(1), 1–34. https://doi.org/10.1016/S0301-0511(00)00051-X

Giedd, J. N., & Rapoport, J. L. (2010). Structural MRI of pediatric brain development: What have we learned and where are we going? *Neuron, 67*(5), 728–734. https://doi.org/10.1016/j.neuron.2010.08.040

Granacher, U., Lesinski, M., Büsch, D., Muehlbauer, T., Prieske, O., Puta, C., ... & Behm, D. G. (2016). Effects of resistance training in youth athletes on muscular fitness and athletic performance: A conceptual model for long-term athlete development. *Frontiers in Physiology, 7*, 164. https://doi.org/10.3389/fphys.2016.00164

Kail, R. V., & Salthouse, T. A. (1994). Processing speed as a mental capacity. *Acta Psychologica, 86*(2), 199–225. https://doi.org/10.1016/0001-6918(94)90003-5

Khan, N. A., & Hillman, C. H. (2014). The relation of childhood physical activity and aerobic fitness to brain function and cognition: A review. *Pediatric Exercise Science, 26*(2), 138–146. https://doi.org/10.1123/pes.2013-0125

Lake, D. A. (1992). Neuromuscular electrical stimulation: An overview and its application in the treatment of sports injuries. *Sports Medicine, 13*(5), 320–336. https://doi.org/10.2165/00007256-199213050-00003

Lloyd, R. S., Cronin, J. B., Faigenbaum, A. D., Haff, G. G., Howard, R., Kraemer, W. J., ... & Oliver, J. L. (2016). National Strength and Conditioning Association position statement on long-term athletic development. *The Journal of Strength & Conditioning Research, 30*(6), 1491–1509. https://doi.org/10.1519/JSC.0000000000001387

Maffiuletti, N. A., Gometti, C., Amiridis, I. G., Martin, A., Pousson, M., & Chatard, J. C. (2000). The effects of electromyostimulation training and basketball practice on muscle strength and jumping ability. *International Journal of Sports Medicine, 21*(6), 437–443. https://doi.org/10.1055/s-2000-3837

Maffiuletti, N. A., Pensini, M., & Martin, A. (2002). Activation of human plantar flexor muscles increases after electromyostimulation training. *Journal of Applied Physiology, 92*(4), 1383–1392. https://doi.org/10.1152/japplphysiol.00981.2001

McAuley, T., & White, D. A. (2011). A latent variables examination of processing speed, response inhibition, and working memory during typical development. *Journal of Experimental Child Psychology, 108*(3), 453–468. https://doi.org/10.1016/j.jecp.2010.08.009

Merletti, R., Rainoldi, A., & Farina, D. (2005). Myoelectric manifestations of muscle fatigue. In *Electromyography* (pp. 233–258). https://doi.org/10.1002/0471678384.ch9

Myer, G. D., Faigenbaum, A. D., Ford, K. R., Best, T. M., Bergeron, M. F., & Hewett, T. E. (2011). When to initiate integrative neuromuscular training to reduce sports-related injuries and enhance health in youth? *Current Sports Medicine Reports, 10*(3), 155–166. https://doi.org/10.1249/JSR.0b013e31821b1442

Newman-Toker, D. E. (2023). *Johns Hopkins University School of Medicine testimony*. https://democrats-energycommerce.house.gov/sites/evo-subsites/democrats-energycommerce.house.gov/files/evo-media-document/newman-toker_witness%20testimony_11.29.2023.pdf

Singh, A. S., Saliasi, E., Van Den Berg, V., Uijtdewilligen, L., De Groot, R. H., Jolles, J., ... & Chinapaw, M. J. (2019). Effects of physical activity interventions on cognitive and academic performance in children and adolescents: A novel combination of a systematic review and recommendations from an expert panel. *British Journal of Sports Medicine, 53*(10), 640–647. https://doi.org/10.1136/bjsports-2017-098136

Span, M. M., Ridderinkhof, K. R., & van der Molen, M. W. (2004). Age-related changes in the efficiency of cognitive processing across the life span. *Acta Psychologica, 117*(2), 155–183. https://doi.org/10.1016/j.actpsy.2004.05.005

Verret, C., Guay, M.-C., Berthiaume, C., Gardiner, P., & Béliveau, L. (2012). A physical activity program improves behavior and cognitive functions in children with ADHD: An exploratory study. *Journal of Attention Disorders, 16*(1), 71–80. https://doi.org/10.1177/1087054710379735

World Medical Association. (2013). World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human subjects. *JAMA, 310*(20), 2191–2194. https://doi.org/10.1001/jama.2013.281053

Received:16.06.2025.
Accepted:20.10.2025.

Correspondence:
Nevena Stupar,
Faculty of Education, Bijeljina, University of East Sarajevo, BiH
e-mail: nevena.stupar@pfb.ues.rs.ba