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Original scientific paper

Effects of Vibrotactile Stimulation on the Control of Muscle Tone and Movement Facilitation in Children with Cerebral Injury

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A B S T R A C T

Afferent signals from the muscle's proprioceptors play important role in the control of muscle tone and in the facilitation of movements. Peripheral afferent pathway enables the restoration of connections with supraspinal structures and so includes mechanism of synaptic inhibition in the performance of normal movement. Different sensory stimuli, as vibrotactile stimulation, excite muscle's proprioceptors which then send sensorimotor information via spinal cord. In this way afferent signals promote cortical control and modulation of movements. The goal of this study is to evaluate the effects of vibrotactile stimulation on the spasticity and motor performance in children with cerebral injury. Subjects included in this study were 13 children who were developing the classification of spastic cerebral palsy. For all children perinatal brain damage was documented by medical reports and neonatal brain ultrasound scan. At the mean age of 3 years and 6 months subject underwent the assessment of motor development by Gross Motor Function Measurement (GMFM-88). Gross Motor Classification System (GMFCS) has been used to classify functions of lower extremities. Therapeutic intervention was conducted once a week during 3 months. All subjects were stimulated with vibrotactile stimuli of 40Hz in duration of 20 minutes in order to reduce spasticity. After the ending of the treatment subjects underwent second assessment of motor performance and the classification of lower extremities functions. The results have shown that there was a significant improvement in motor performance, what has been seen in the facilitation of rotations, better postural trunk stability and head control and in greater selectivity of movements. Further randomized, control trial investigations with bigger sample and included spasm scale are needed to gain better insight in the role of vibrotactile stimulation in the facilitation of normal movements.

Key words: *vibrotactile stimulation, spasticity, movement facilitation, cerebral injury*

Introduction

The importance of rehabilitation in cerebral injury is widely recognized, but the type of therapy, the timing and the duration of intervention are still under debate[1–3]. One of the potential interventions for successful repair of existing cerebral injury involves plasticity. Stimulation and development of alternative brain pathways can lead to resumption and restoration of the functions in the injured brain areas[4]. In response to alterations in the cell's environment, such as the stimulation from the sensory systems, the functional anatomy of brain synapses is constantly changing. As these changes are biological basis for learning during child development, the brain is able to acquire new or improved skills[4]. Considering this, sensory stimulus can be used to improve or to achieve control in motor coordination and movements. Although investigations using specific sensory inputs to correct the motor impairments and functions are still in progress, the importance of sensory stimulus in motor performance is recognized.

Injury in the developing brain motor system shows following hallmarks: spasticity, muscle weakness, involuntary movements and loss of control in muscle coordination. In this situation muscles and peripheral nerves are not damaged, but the brain is unable to provide the delicate control that is crucial in ensuring the multitude

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of coordinated small and large muscle movements necessary for common daily living activities.

Cerebral palsy is one of the most common causes of spasticity in children. Spasticity is a clinical sign with associated symptoms that commonly occurs in neurological conditions associated with an upper motor neuron lesion[5]. It is essentially a pathologic increase in muscle tone or tonic stretch reflex. The most commonly used definition is that of Lance: 'a motor disorder characterized by a velocity dependant increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks, resulting from hyper-excitability of the stretch reflex, as one component of the upper motor neuron syndrome'[6]. In spasticity there is a constellation of positive clinical findings, such as increased tone, hyperactive reflexes, extensor plantar responses and clonus, and negative clinical findings, such as lack of agility, loss of selective motor control and poor cordination[7]. These clinical signs are the consequence of a chronic loss of inhibitory suprasegmental inputs, producing the hyperactivity of alpha motoneuron. This results in abnormal processing of afferent input at the spinal cord[7]. Electrical signals transmitted along the axon prompt the release of acetylcholine from the nerve terminal at the neuromuscular junction[8]. Acetylcholine binds to receptors on the muscle cell membrane, in this way opens ion channels and produce muscles contraction. When muscle tone is excessive, disrupting spinal reflex arc at any point along its course, uninjured brain will reduce excessive gain through feedback loop what results in reduction of muscle tone[9]. Any pathological process that disrupts these inhibitory inputs may result in spasticity[8].

The aim of reducing excessive muscle tone is to improve ease of motion and prevent soft tissue and bones deformity in the longer term. Improving ease of motion aids active function in the limbs. Muscle tone reduction also has other benefits such as comfort, positioning and care giving. This reflects on life quality of a child and a family. In the broadest terms, the goals of any spasticity treatment plan are to maximize active function and prevent secondary problems such as pain, subluxation and contracture[10].

Vibrotactile stimulation

Vibroacoustic therapy uses sound vibration for proprioceptive and tactile stimulation. The physical effect of the sound is used as a stimulus. Sound frequencies that are transmitted into vibroacoustic devices become vibrations felt by the body. Vibroacoustic therapy involves pulsed, sinusoidal low frequency sound within a range of 30–120Hz. The pulsed, sine wave which is used has only one frequency. A sine wave, or pure tone, flows with a precisely matched increase and decrease of amplitude. These pure tones are used because they do not produce overtones that could affect the vibration experience or alter the frequency dose. The purpose of power pulsation is to prevent muscle contraction which is commonly caused by continuous stimulation. With the sound pulsating slowly, this effect can be avoided and relaxation is achieved instead[11]. Low frequency range is most strongly felt in the body and may contribute to symptom relief[12].

A frequency of 40Hz has been found to be effective in rehabilitation towards brain injuries and it is widely used in vibroacoustic method as basic frequency[13]. Llians and Ribary[14] have found that in some exceptional cases, such as beginning Alzheimer disease and some brain injuries, the 40Hz wave disappears or it is disturbed. Llians has suggested that with auditory stimulation using 40Hz sound, it is possible to reinforce this thalamus frequency. He has also established that 40Hz stimulation through the body has potential in the rehabilitation of brain injured clients.

Skille[12], who developed vibroacoustic method, was primarily focused on the effects of sound vibration on the reduction of muscle tone. These findings were confirmed by Wigram[13], with the use of vibroacustic therapy with cerebral palsy adult patients to reduce high muscle tone. Boakes[15] has assumed that low frequency vibrations excite muscle's proprioceptors which then send sensorimotor information via spinal cord. This afferent information enables the restoration of connections with supraspinal structures and so they include mechanism of synaptic inhibition in the performance of normal movement. The effects of vibroacoustic therapy on Parkinson's disease were investigated in a single-blind, randomized study in Spain[16]. The results demonstrated that moderate gains were made in motor abilities. The positive effect of vibrotactile stimulation on rigidity and tremor was observed in persons with multiple sclerosis[17]. In a study of vibroacoustics following the suctioning of neonates, Burke et al.[18] found that vibrotactile stimulation increased the amount of time infants spent in a quiet alert state, increased sleeping time and improved oxygen saturation levels. The transmission of vibrations to the biological system can lead to stimulation of skin receptors, muscle spindles, vestibular system, changes in thalamus and somatosensory cortex and to changes of neurotransmitter and hormone concentrations[17].

The pilot study reported here aimed to identify the effects of vibrotactile stimulation on the control of muscle tone and movement facilitation in young children who were developing the classification of spastic cerebral palsy. The primary objective was to determine whether vibrotactile stimulation could improve gross motor function in children with cerebral injury.

Materials and Methods

Participants and study design

Thirteen children were enrolled into the study. Inclusion criteria for the study were (1) a perinatal brain damage documented by medical reports and neonatal brain ultrasound scan; (2) developing classification of spastic cerebral palsy (unilateral and bilateral) by neurological evaluation (3) a chronological age between 3 and 4 years old at the beginning of the study and (4) the absence of planned surgery, of significant medical problems or other clinical factors that might bias the rehabilitation program. Recruitment was from patient referred to the Day care center for rehabilitation – Mala kuća, Zagreb, Croatia between 2006 and 2008. The present study was discussed with the child's parents and, if the parents were willing, the child was enrolled into the study. Informed consent for the study was obtained from both of the child's parents, who had been fully informed of the study's design and aims and the characteristics of the intervention.

Outcome measures

Children were assessed at baseline and after 12-week intervention period. The assessment was performed by a trained assessor in a familiar location.

The primary outcome was gross motor function as assessed by global changes in the Gross Motor Function Measurement (GMFM), standardized, valid and reliable tool for classifying gross motor function in children with cerebral palsy[19,20]. The GMFM assesses motor function in five dimensions: (A) lying and rolling; (B) sitting; (C) crawling and kneeling; (D) standing and (E) walking, running and jumping. Each of 88 items is scored on a 4-point scale; the score for each dimension is expressed as a percentage of the maximum score. The global score is the average of the five percentages. Gross Motor Classification System (GMFCS) has been used to classify function of lower extremities in five levels: (I) walks without limitations; (II) walks with limitations; (III) walks using a hand-held mobility device; (IV) self mobility with limitations; (V) transported in a manual wheelchair.

Interventions

Therapeutic intervention was conducted once a week during 12-week period. All children were stimulated with vibrotactile stimuli in order to reduce spasticity. During intervention treatment children were placed on the vibromusic bed-pad (VISIC bedpad-VSM 10, Acouve Laboratory Inc, Japan) in supine position with head in the midline. The equipment used for low frequency sound transfer were vibro transducers mounted in the bed-pad and connected to vibro-music amplifier and sound source, as it is shown in Figure 1[21]. The equipment was programmed to send out the stimulus gradually. Original Multivib Olav Skille's CD of 40 Hz sinus wave with sinusoidal amplitude variation (6,8 seconds between peaks) was used for each treatment session in duration of 20 minutes. Intensity level was always over vibration sensor peception.

Any additional visual or auditory stimuli where removed from the room where the intervention took the place, in order to avoid a influence on the procedure. During the intervention period the therapist was staying with the child in the room. Before the sound stimuli was introduced, the therapist explained the child what will happen and that he will stay during intervention in the room. In the beginning of treatment children needed support with pillows in order to maintain appropriate

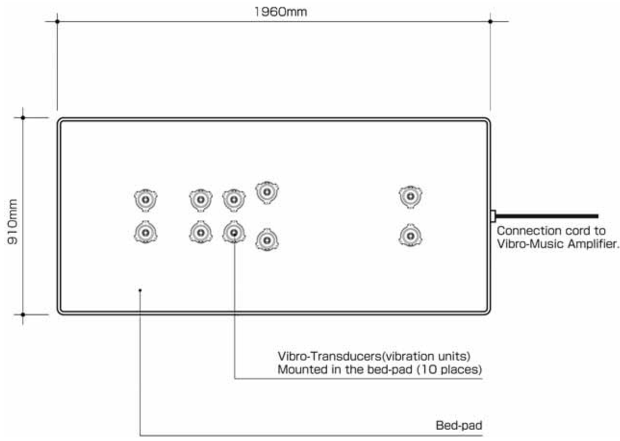

Fig. 1. The scheme of vibromusic bed-pad (VSM-10).

postural position. During the procedure children lied calmly and no other activities took place. All children attended their regular habilitation program (physiotherapy, occupational therapy, speech therapy, visual stimulation) during intervention period.

Statistical analysis

Statistical analysis was conducted with significance power of 95% ($\alpha=0.05$). As distribution did not satisfy the parametric assumptions, non-parametric Wilcoxon Matched Pairs test was used to compare the change in GMFM between baseline and 12-week follow-up. The Wilcoxon Matched Pair test only supplies p-values. To

TABLE 1
DEMOGRAPHIC, CLINICAL AND ULTRASOUND SCAN DATA

Patient	Sex	Neurological Evaluation	Ultrasound Scan Features	GMFCS (Baseline Study)
1	F	BSCP	PVL III	V
2	M	USCP	CYSTIS	III
3	M	BSCP	IVH II	III
4	M	BSCP	PVL III	V
5	M	BSCP	PVL III	V
6	F	BSCP	PVL III	V
7	M	BSCP	IVH III	V
8	M	BSCP	PVL III	V
9	F	BSCP	IVH II	IV
10	M	BSCP	PVL III	V
11	F	BSCP	IVH III	V
12	M	BSCP	PVL III	V
13	M	BSCP	PVL III	V

BSCP – bilateral spastic cerebral palsy, USCP – unilateral spastic cerebral palsy, PVL – periventricular leucomalacia, IVH – intraventricular hemorrhage, GMFCS – gross motor classification system, III – walks using a hand-held mobility device, IV – self mobility with limitations, V – transported in a manual wheelchair

TABLE 2
DESCRIPTIVE STATISTICS DATA

Variable	Valid N	Median	Minimum	Maximum	Lower Quartile	Upper Quartile	Percentile 10%	Percentile 90%
GMFM before	13	9.50	2.74	49.39	7.05	13.86	3.92	44.37
GMFM after	13	16.60	8.66	56.35	14.37	20.47	9.45	55.00

GMFM before – gross motor function measurement total score before intervention
GMFM after – gross motor function measurement total score after intervention

gain insight in effect sizes and their confidence intervals, we calculated the lower and upper percentiles. Results with $p<0.05$ were considered statistically significant. For statistical analysis of descriptive parameters in GMFCS scale, Pearson χ^2-test was used. The analyses were done with the program STATISTICA version 6.1.

Results

Demographic and clinical characteristic of the children are shown in Table 1. Ultrasound scan features have shown that 8 of 13 children (62%) had PVL 3 and 31% of children had IVH 2–3. One child had cystis. Based on neurological evaluation, 12 children have been developing classification of bilateral spastic cerebral palsy (BSCP) and just one child unilateral spastic cerebral palsy (USCP). Classification of CP was done according to the Surveillance of Cerebral Palsy in Europe (SCPE) proposal.

Medians and ranges for the GMFM total score before and after 12 weeks-long interventions are presented in Table 2. Before the intervention, median for the GMFM total score was 9.50 (3.92–44.37) and after intervention it was 16.60 (9.45–55.00). At a baseline 77% (10 subjects) of children were classified to a level V, 8% to a level IV and 15% to a level III (Table 3).

TABLE 3
FREQUENCY TABLE: GMFCS BEFORE

Category	Count	Cumulative Count	Percent	Cumulative Percent
V	10	10	76.92308	76.9231
IV	1	13	7.69231	100.0000
III	2	12	15.38462	92.3077
Missing	0	13	0.00000	10.0000

V – transported in a manual wheelchair, IV – self mobility with limitations, III – walks using a hand-held mobility device

TABLE 4
WILCOXON MATCHED PAIRS TEST

Pair of variables	Valid N	T	Z	p-level
DIM A before & DIM A after	13	0.00	3.059412	0.002218
DIM B before & DIM B after	10	0.00	2.803060	0.005062
GMFM before & GMFM after	13	0.00	3.179797	0.001474

DIM A – lying and rolling, DIM B – sitting, GMFM – gross motor function measurement total score

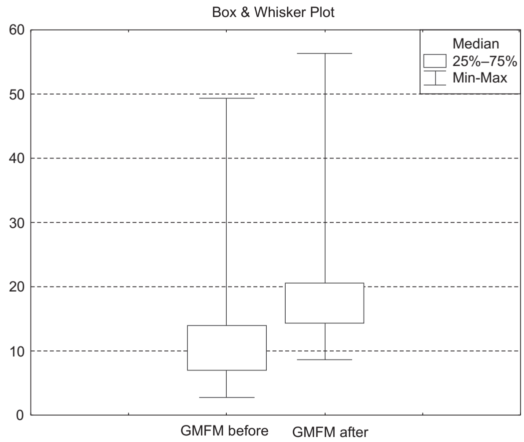

Fig. 2. Changes in gross motor function measurement total score before and after interventions. Data are presented as box plots. GMFM before – gross motor function measurement total score.

The results presented in Table 4 show that after 12 weeks of intervention there was a significant improvement in total GMFM score (z=3.17, p=0.00), as well as on dimension A (z=3.05, p=0.00) and dimension B (z= 2.80, p=0.00). There were insufficient data for a meaningful comparison of the effect of intervention treatment on dimensions C, D and E. The changes in central tendencies before and after treatment (median, minimum, maximum, lower and upper quartile) for dimensions A

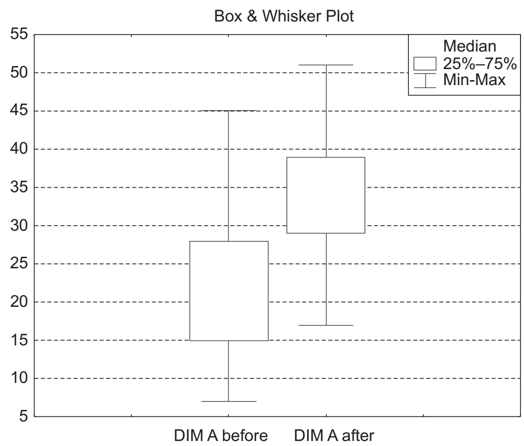

Fig. 3. Changes in dimension A before and after interventions. Data are presented as box plots. DIM A – lying and rolling.

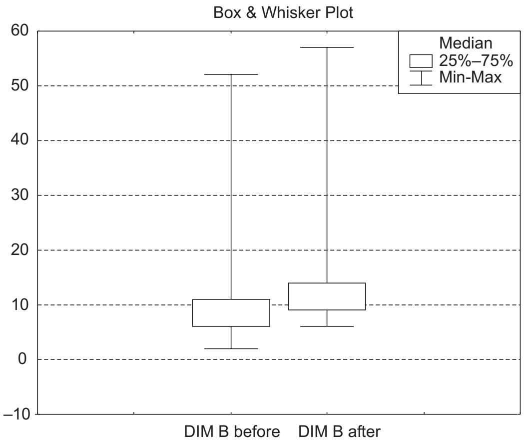

Fig. 4. Changes in dimension B before and after interventions. Data are presented as box plots. DIM B – sitting.

TABLE 5
PEARSON χ^2 TEST FOR TESTING DIFFERENCE IN GMFCS LEVELS BEFORE AND AFTER INTERVENTIONS

	χ^2	df	p
Pearson χ^2	26.0000	df=6	p=0.00022
M-L χ^2	17.86439	df=6	p=0.00658

and B and for total GMFM score are presented in Figures 2, 3 and 4.

The results in Table 5 show that there was a significant difference between GMFCS levels of children before and after intervention (df=6, p=0.00). Out of 13 children, 6 changed their GMFM level (46%), but none were reclassified to the lower level. 30% of children that were classified to the level V, after 12 weeks-long interventions reclassified to the level IV. Children at the level IV and III were also reclassified to one level up (Figure 5).

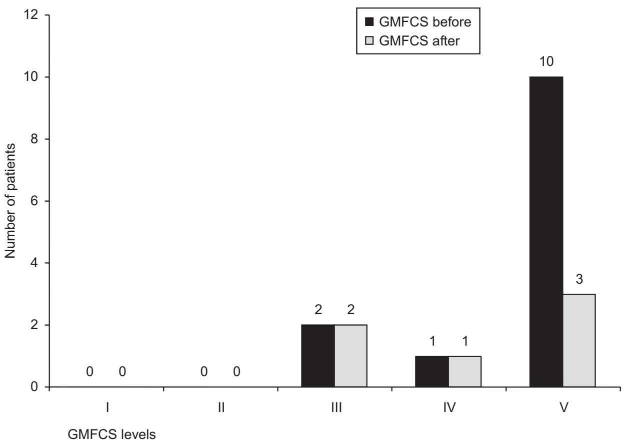

Fig. 5. Changes in gross motor function classification system over the three months-long interventions. I – walks without limitations, II – walks with limitations, III – walks using a hand-held mobility device, IV – self mobility with limitations, V – transported in a manual wheelchair.

Discussion

The result of our study shows that vibrotactile stimulation may enhance gross motor performance in children with spastic cerebral palsy. As proprioception is an important component of motor control, one can expect that vibrotactile stimulation, recognized by the brain cortex and processed in central nervous system will act on motor system. In this way peripheral afferent pathway enables the restoration of connections with supraspinal structures and includes mechanism of synaptic inhibition in the performance of normal movement. This concurs with results of Ahlborg et al. who reported that 8 weeks of intervention with whole body vibration can increase gross motor performance in adult patients with spastic cerebral palsy without negative effect on spasticity[22]. Semler et al. have also found that adolescents affected with cerebral palsy showed a reduction of spasticity and improved functional motor pattern after vibration stimulus[23]. It is important to notice that to our knowledge, presented study is the first research dealing with effects of vibrotactile stimulation on motor performance in children with cerebral palsy. The number of studies on participants with neurological pathologies and diseases is very limited. Previously published data on vibration as a proprioceptive stimulus and its effect on spasticity were carried out on the sample of adult patients[13,24]. Therefore, it was hard to make comparison in effect size between our data and data from other published studies. However, the results show that the improvement in dimension A (lying and rolling), dimension B (sitting) and in GMFM total score was significant. This was observed in the facilitation of rotations, enhanced postural stability, and better head control and in greater selectivity of movements. The limitation of the presented study was the absence of control group in order to specify the intervention effect on outcomes and also to exclude the influence of neurodevelopment. But, considering that at a baseline 77% of children were classified to the lowest level of motor functioning (level V) and that after 12 weeks-long intervention 30% of them were reclassified to a level IV, we might assume that this clinical progress is the consequence of vibrotactile stimulation. As shown in the literature, change score of 1.6 points on the GMFM is clinically meaningful and change score of 3.7 points discriminates moderate improvement from a great improvement[25]. In our study the improvement on the GMFM was 7.1 points, so we believe that our results indicate a clinically meaningful improvement in gross motor function. Based on Madou and Cronin's review about effects of whole body vibration on physiological capability in special populations, it has been proven that vibration has more beneficial effects on balance, stability and gait in comparison with conventional treatment (physiotherapy and resistance training)[26].

Current evidence does not allow an explanation of the specific neural adaptations that accompany a vibration treatment. Delecluse et al. suggested that vibration might alter the connectivity between corticospinal cells and spinal motoneurons[27]. Interneurons in spinal cord receive input from afferent and descending fibers, the fibers of other interneurons and ultimately influence the activity of motoneurons. The sensory stimulation of proprioceptive pathways that are the basis in vibration intervention seems hereby crucial. The consequence of repetitive sensory stimulation via proprioceptors might be the rearrangement of motor control strategies. This can result in an improvement of postural stability and suggests that vibration stimulus has a great potential in a therapeutic context where it may enhance muscular performance[17,28].

It is also important to consider the influence of vibrotactile stimulation on central motor structures. It has been shown that the primary and secondary somatosensory cortex, together with the supplementary motor area (SMA), constitute the central processing unit of afferent signals[29]. Vibration that is capable of producing kinesthetic illusion activates the supplementary motor area, the caudal cingulate motor area and area 4a of the brain[28]. Moreover, the supplementary motor area of the brain that is activated by vibration is also activated early during self-initiated movements[30]. Accordingly, the vibration treatment provides external stimulus that might normalize supplementary motor area activation[31]. It is well described that SMA is important for generating and controlling complex movements, however it is unclear to which extent SMA activation generated during vibration treatment can influence post-treatment motor control[32].

Vibration represents a strong stimulation of musculoskeletal structures due to the need to quickly modulate muscle stiffness to accommodate the vibratory waves. The primary endings of the muscle spindle are more sensitive to vibration than are secondary endings and Golgi tendon organs. Anyway, vibration is perceived not only by neuromuscular spindles, but also by the skin, the joints and secondary endings[33]. Consequently these sensory structures likely facilitate the γ-system during the application of vibration and enhance the sensitivity of the primary endings[34]. These finding suggest that vibration could represent an effective intervention for enhancing neuromuscular performance.

Research in vibroacoustics and its applications have demonstrated that this nonpharmacological, noninvasive therapy offers sensory stimulation, reduces muscle tones, improve motor abilities and assists in the neurorehabilitation of motor system. Although the presented results identify, at least to some extent, the effect of vibrotactile stimulation on the control of spasticity and movement facilitation through improved motor performance, there are implications for further research that will focuse on the measurement of spasticity and specify these findings for neurorehabilitation of children with spastic cerebral palsy.

Conclusion

The repair of injuries in the motor system of the developing brain is an exciting area of active research that has captured the attention of neuroscientists. Research answers in this field will provide the basis both for clinical experiments that address the repair of specific cerebral injuries and for the development of methods to improve function in persons with disabilities caused by cerebral injury.

The result of this pilot study indicated that vibrotactile stimulation may have positive influence on movement facilitation and enhance gross motor performance in children with cerebral injury. There seems to be great potential for the use of vibrotactile stimuli in the field of neuromuscular rehabilitation. Even though mechanisms of the effects are not fully clarified, this method could offer new approaches in the rehabilitation of neurological diseases and neuromuscular disturbance.

Our present study has a few limitations. Firstly, intervention treatment was embedded into a multidisciplinary setting and secondly, there was no comparison with patients without intervention treatment. Therefore the impact of nonspecific factors on intervention outcome cannot be determined. Further randomized, control trial investigations with bigger sample and included spasm scale are needed to gain better insight in the role of vibrotactile stimulation in the neurorehabilitation of motor system. The combination of these functional outcome measures and a quantitative measurement of spasticity will further delineate the contribution of vibrotactile stimulation on the control of spasticity and motor performance in children with spastic cerebral palsy.

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UTJECAJ VIBROTAKTILNE STIMULACIJE NA KONTROLU SPASTIČNOSTI I NA FACILITACIJU POKRETA U DJECE S CEREBRALNOM OZLJEDOM

SAŽETAK

Aferentni signali iz mišićnih proprioceptora igraju važnu ulogu u kontroli spastičnosti i u facilitaciji pokreta. Periferni aferentni putovi omogućuju obnavljanje veza između supraspinalnih struktura i tako uključuju mehanizam sinaptičke inhibicije u izvođenje normalnog pokreta. Različiti osjetilni podražaji, kao što je vibrotaktilna stimulacija, pobuđuju mišićne proprioceptore koji kroz kralježničnu moždinu šalju senzomotoričku informaciju. Na ovaj način aferentni signali sudjeluju u kortikalnoj kontroli i modulaciji pokreta. Cilj ovog istraživanja je ispitati utjecaj vibrotaktilne stimulacije na spastičnost i motoričku izvedbu u djece s cerebralnom ozljedom. 13 djece, koja su razvijala klasifikaciju spastične cerebralne paralize je uključeno u ovo istraživanje. Perinatalna ozljeda mozga dokumentirana je medicinskom dokumentacijom i nalazima neonatalnog ultrazvuka. U prosječnoj dobi od 3 godine i 6 mjeseci izvršena je procjena motoričkog razvoja testom grubih motoričkih funkcija (GMFM-88). Za klasifikaciju funkcija donjih ekstremiteta korišten je klasifikacijski sustav GMFCS (Gross Motor Classification System). Terapijska intervencija provođena je jednom tjedno kroz tri mjeseca. Sva su djeca izlagana vibrotaktilnom podražaju u trajanju od 20 minuta kako bi se utjecalo na smanjenje spastičnosti. Nakon završetka tretmana izvršena je druga procjena motoričkog razvoja kao i klasifikacija funkcija donjih ekstremiteta. Rezultati su pokazali značajan napredak u motoričkom izvođenju, što je vidljivo u facilitaciji rotacija, boljoj posturalnoj kontroli i kontroli glave te u povećanoj selektivnosti pokreta. Potrebna su daljnja istraživanja s kontrolnom skupinom, većim uzorkom i skalama spazma kako bi se dobio jasniji uvid o utjecaju vibrotaktilne stimulacije na facilitaciju normalnog pokreta.