

Efficacy of trans-mastoidal vestibular galvanic stimulation in improvement gait performance and upright postural stability in hemiplegic C.P. children

Ahmed M. Azzam

Department of physiotherapy for developmental disturbance and pediatric surgery, Faculty of physical therapy, Cairo University, Giza, Egypt

ABSTRACT

Objectives: This work was carried out to investigate the efficacy of galvanic vestibular stimulation in improving gait performance and upright postural stability in hemiplegic cerebral palsy children. **Method:** Thirty children were enrolled in this study and randomly assigned into two groups; group A (galvanic vestibular stimulation plus vestibular training program), and group B (vestibular training program). Stride length and time, walking speed tests and modified Ashworth, pediatric balance scales were used to detect and follow the walking performance and upright postural stability. This measurement was taken before initial treatment and after 12 weeks of treatment. The children parents in both groups A and B were instructed to complete 3 hours of the home routine program. **Results:** Data analysis was available on the 30 hemiplegic cerebral palsied children participated in the study. The difference between pre and post-treatment results was significant representative in stride length , time and walking velocity, spasticity changes and pediatric balance scores in study groups while insignificant improvement in control groups. **Conclusion:** The combined vestibular training program and trans-mastoidal vestibular galvanic stimulation are suggested in improving walking performance and upright postural stability in a static and dynamic situation. So this selective physiotherapy approach may be used as a strong choice for improving walking and balance abilities in hemiplegic C.P children.

Keywords: galvanic vestibular stimulation- cerebral palsy-walking performance

Introduction

Central nervous system lesion which occurs in cerebral palsy patients lead to impaired postural reaction mechanism, loss of reciprocal inhibition mechanism, muscle tone disturbance, impaired coordination mechanism and failure of posture stabilization.

Poor balance mechanism is the direct source of the defective motor and functional skills acquisition and motor development delay^{1,2,3}

learning process through Sensory feedback is the plasticity way for continuous modifications of neural connections. Environmental manipulation and external stimulation reshape the neural network patterns through synaptic competition mechanism with the greatest activated synaptic connections become the winner and gain the skill and the lowest activated become the loser. Throughout of life there is an alteration of the synapses functional characteristics according to the new experience and skills plus environmental elements and variant situations or occurring CNS lesion.⁴ Brain plasticity can occur at every lifetime because the CNS is continually remodeling via synaptic reorganization. So vestibular restoration therapy rely on the active participation which produces anatomical and permanent changes in the synaptic network of the neural circuits which produce behavioral changes on the postural stability.^{5,6,7,8,9,10}

Utilization of vestibular galvanic electric stimulation on the mastoid process via placing of anode electrode on the mastoid process in the similar side of body sway and the cathode on the other side. This will activate Na^+ channels opening lead to depolarization of vestibular afferent nerve which produce modulation of the afferent vestibular signals by raising firing rate of the vestibular afferent on the cathode side and reducing the excitation degree on the anodal side which leading to deviation of the posture toward anodal side^{11,12,13}. GVS has a positive effect on the balance control via improve balance response time, decreasing the lateral and A-P sway in static balance together with improving dynamic balance performance and correcting the abnormal perception sway and motor response¹⁴. The anticipatory postural control was improved after application GVS via modulating the vestibulospinal tract signals and activation of vestibular-related sensory areas.¹⁵

During walking the antigravity muscle tonus (γ and α motor neurons)were modulated by the vestibulospinal and reticulospinal tracts so by the application of GVS will increase the vestibulospinal tract activity which transmitted to the antigravity muscles increasing their excitability leading to increasing of stride length and walking speed¹⁶⁻²⁷

Material and Methods

Subjects

30 children from the two sexes with hemiplegic C.P. children were joined in this study, aged 5 to10 years at a time of enrollment due to the children in this age could participate in pediatric balance scale graduations. Children could walk with assistance, On the other hand, C.P. Children that run up against the involvement rules were derived out if they had: preceding BoNT-A dose in the L.L or U.L in the last 12 months or had surgical tendon or muscle lengthening operation.

Children were selected randomly to the study group (A) taken vestibular galvanic electric stimulation plus vestibular training approach while the control group (B) taken vestibular training approach only. The individual-based vestibular galvanic electric stimulation treatment sessions of 30 minutes were conducted day after day for 3 months in a physiotherapy treatment room after the vestibular training period for the group (A). Also, children in the study group were subjected to home regular program 3 hours daily for the 3 months treatment period. The control group (B) received a vestibular training program only

Outcome measurements

1-Gait speed test:

It was used to evaluate the walking speed by determining a distance of 10 meters which evaluates functional vestibular abilities. Measuring tap and stopwatch tools were needed to measure the walking speed. Starting and finishing areas of one meter

were used to build up the maximum speed and decelerate of the speed. The average of 3 trials results was recorded pre and post treatment²⁸.

2-Modified Ashworth scale:

It was used to evaluate and follow up the degree of muscle tone disturbance pre and post-treatment.

3-Pediatric balance scale:

It was used to evaluate functional balance abilities. It consists of 14 items each one is scored on a 5-point scale with zero scores indicate to the child cannot achieve the task without assistance and 4 scores indicate to independence in performing the ability.

The highest score is 56 points(the summation of the scores in all items).

The points from 41-55 indicate to the independent child

The points from 21-40 indicate to the child need assistance

The points 20 or below indicate to the child need wheelchair^{29,30}

4-Stride length and stride time measurements:

stride length is the extension from the toe of the foot (starting position) to the toe of same foot (ending position), or from the heel to heel of the same foot **was measured by tape measurment**. The stride time was detected by stopwatch. 10-meter distance (about 8 steps) was calibrated to evaluate the stride length before and after treatment. Stride time could be calculated by counting time required to perform walking in the calibrated distance.

Intervention

For all children, the treatment was handling three times weekly, for 3 months. Each session persists for 90 minutes (30 minutes vestibular galvanic electric stimulation for study group plus 60 minutes for a vestibular training program for each group)in a

physical therapy room, in addition to 3 hours of the home regular program, 7 days a week around the treatment duration

Both groups (A and B) received a vestibular training program, like the following:

1-With the eyes closed: concentration on vestibular system training through an unstable surface to isolate proprioceptors and perform postural reaction training(righting +equilibrium+ protective reaction training) through medical balls and balance board of different sizes.

2-With the eyes opened then closed slow then rapid training. The child performs dynamic vestibular training forward to the mirror by walking sideways with feet followed each other then walk on one line then walk by passing foot to one another.

3-Static training to vestibular system by performing proximal stabilization in a quadruped, kneeling, half kneeling, standing.

4-Proprioceptive training with vestibular training by standing on one foot with eyes opened then closed.

5-Equal weight shift transfer by starting the big base of support then gradual decrease of BOS(**Base of support**) without disturbance then with disturbance-with eye opened then eye closed-with hand support then without.

6-Step forward including or excluding disturbance, with eyes opened then closed on different directions and surfaces.

7-Weight-bearing with upper extremity functional training as hand skills training (from sitting-standing-kneeling) as grasping, voluntary release, reaching, hand manipulative skills, bilateral hand use, and eye-hand coordination training.

8-Changing positions from non-weight bearing to weight bearing and opposite and from static to dynamic and opposite.

9-Upside training anteroposterior movement and lateral movement then rotatory movement.

10-Swing therapy anteroposterior movement and lateral movement then rotatory movement.

11-Biodex stability system training.

12-Perturbation with different positions (quadruped-kneeling-half-kneeling-standing, holding a big medical ball with maintaining posture stability, stand against the corner, stand with holding stand bar and manual support standing).

13-Jumping training with trampoline²⁸.

The experimental group (group A) received vestibular galvanic electric stimulation following:

vestibular galvanic electric stimulation is a noninvasive technique that sending a direct electric message to the vestibular receptors (3semicircular ducts and the two otolith organs utricle and saccule) aiming for enhancement of gait performance. By locating a target to the child and starting point on a sheet and placed the anodal electrode on the mastoid process on the side of paralysis and the cathode on the other mastoid process. The elastic headbands stabilized the two stimulating electrodes. The physiotherapist asks the child to go with holding the child from his upper parts of the shoulder in the similar time of turning on the direct current with the intensity of 0.5 mA intensity with long latency more than 200 ms for 30 minutes. There is deviation of the posture on the anodal side till the child reaches to the target or the child could use a pediatric treadmill withholding of hand support and ask the child to slowly walk with the similar time of turning the apparatus on.

Results:

Patients characteristics:

Table 1 display the demographic and analytic traits of all patients. There were 13 boys (43,33%) and 17 girls (56.67%) and in term of right-hand dominance reported in 17 patients (56.67%), and also 13 patients (43,33%) were left-hand dominance. There was no representative change within both groups regarding age ($p=0.8816$), to sex ($p=0.7240$) and in term of hand dominance ($p=0.4814$).

Table 1) patients characteristics

Variables	Study group N=15	Control group N=15	P-value
Age	7.80±1.26	7.73±1.16	0.8816
Sex N%			
Boys	7 (46.67%)	6 (40%)	0.7240
Girls	8 (53.33%)	9 (60%)	

Hand dominance			
N%			0.4814
Right	9(60%)	8(53.33%)	
Left	6(40%)	7(46.67%)	

Changes in stride length

Mean test scores and SD for both groups are demonstrated in table 2. The mean record of stride length level in the two groups at (pre- and post-treatment levels) was worthless ($p>0.05$). The average improvement of stride length level had a tendency to be extremely representatives improvement in the experimental group (3.433 ± 0.961 versus 2.967 ± 0.990 , $p=0.0005$) while worthless representatives in the control group (3.100 ± 0.828 versus 2.967 ± 0.915 , $p=0.1038$). The percentage of improvement of stride length level was (15.706%) in the study group compared to the (4.483%) in the control group.

Table2: The average test of stride length level in both groups.

Stride length level	Study group Mean \pm SD	Control group Mean \pm SD	P-value (within groups)
Pre-treatment	2.967 \pm 0.990	2.967 \pm 0.915	1.000
Post-treatment	3.433 \pm 0.961	3.100 \pm 0.828	0.3176
Improvement%	15.706%	4.483%	0.0389
P-value (within groups)	0.0005	0.1038	

Changes in walking velocity

Mean test scores and SD for the both are demonstrated in table 3. The mean record of walking velocity level in the two groups at (pre-treatment) was worthless ($p>0.05$) while the two groups had a representatives improvement in walking velocity at post-treatment level ($p<0.05$). The average improvement of walking velocity level had a tendency to be extremely representatives improvement in the study group (6.93 ± 0.70

versus 5.8 ± 0.86 , $p=0.0001$) while worthless representatives regarding control group (5.80 ± 1.21 versus 5.67 ± 1.29 , $p=0.1643$). The percentage of improvement of walking velocity level was (19.48%) in the study group compared to the (2.29%) regarding the control group.

Table 3: The average test of walking velocity level in both groups.

Walking velocity level	Study group Mean \pm SD	Control group Mean \pm SD	P-value (within groups)
Pre-treatment	5.8 ± 0.86	5.67 ± 1.29	0.7419
Post-treatment	6.93 ± 0.70	5.80 ± 1.21	0.0039
Improvement%	19.48%	2.29%	0.0004
P-value (within groups)	0.0001	0.1643	

Changes in pediatric scale

Mean test scores and SD for both groups are presented in table 4. The mean record of pediatric scale score in the two groups at pre-treatment was worthless ($p>0.05$) while the two groups had a significant improvement in pediatric scale score post-treatment ($p<0.05$). The average improvement of pediatric scale score had a tendency to be extremely representatives improvement in the study group (41.80 ± 1.32 versus 36.53 ± 3.07 , $p=0.0001$) than regarding control group (36.07 ± 2.91 versus 36.53 ± 2.72 , $p=0.0558$). The percentage of improvement of pediatric scale score was (14.43%) in the study group compared to the (1.2%) regarding control group.

Table 4: The average test of pediatric scale score in both groups.

pediatric scale score	Study group Mean \pm SD	Control group Mean \pm SD	P-value (within groups)
Pre-treatment	36.53 ± 3.07	36.53 ± 2.72	0.3531
Post-treatment	41.80 ± 1.32	36.07 ± 2.91	0.0001
Improvement%	14.43%	1.2%	0.3275
P-value (within groups)	0.0001	0.0558	

Changes in spasticity degree

Mean test scores and SD for both groups are demonstrated in the table5. The mean record of spasticity degree level in the two groups at (pre-treatment) had significant improvement ($p<0.05$) while both groups had an worthless improvement in spasticity degree at post-treatment level ($p>0.05$). The average improvement of spasticity degree level tended to be extremely representatives improvement in the study group. (1.47 ± 0.52 versus 2.40 ± 0.63 , $p=0.0001$) while worthless regarding control group (1.53 ± 0.52 versus 1.60 ± 0.51 , $p=0.3343$). The percentage of improvement of spasticity degree level was (38.75%) in the study group compared to the (4.375%) regarding control group.

Table 5: The average test of spasticity degree level in both groups.

Spasticity degree level	Study group Mean \pm SD	Control group Mean \pm SD	P-value (within groups)
Pre-treatment	2.40 ± 0.63	1.60 ± 0.51	0.0007
Post-treatment	1.47 ± 0.52	1.53 ± 0.52	0.7263
Improvment%	38.75%	4.375%	0.0009
P-value (within groups)	0.0001	0.3343	

Changes in stride time

Mean test scores and SD for both groups are demonstrated in table 6. The mean record of stride time level in the two groups at (pre-and post-treatment level) was worthless ($p>0.05$). The average improvement of stride time level had a tendency to be extremely representatives improvement in the study group (11.07 ± 1.91 versus 12.93 ± 2.25 , $p=0.0002$) than regarding control group (12.27 ± 1.58 versus 12.47 ± 1.55 , $p=0.0824$). The percentage of improvement of stride time level was (14.385%) in the study group compared to the (1.6%) regarding control group.

Table 6: The average test of stride time level in both groups.

Stride time level	Study group Mean \pm SD	Control group Mean \pm SD	P-value (within groups)
Pre-treatment	12.93 ± 2.25	12.47 ± 1.55	0.5140

Post-treatment	11.07±1.91	12.27±1.58	0.0710
Improvement%	14.385%	1.6%	0.0001
P-value (within groups)	0.0002	0.0824	

Discussion

The results of the present study suggest that trans-mastoidal vestibular galvanic stimulation might be useful to enhance independency in gait performance and upright postural stability in hemiplegic C.P. children. The effects of direct electrical vestibular stimulation plus manual vestibular training are more benefits for global function Improvement than manual vestibular training only. The study group pre and post treatment showed increase at the stride length level (3.433 ± 0.961 versus 2.967 ± 0.990 , $p=0.0005$) while insignificant in the control group (3.100 ± 0.828 versus 2.967 ± 0.915 , $p=0.1038$). Also the study group pre and post treatment showed increase at the walking velocity (6.93 ± 0.70 versus 5.8 ± 0.86 , $p=0.0001$) while worthless representatives regarding control group (5.80 ± 1.21 versus 5.67 ± 1.29 , $p=0.1643$). In addition to the study group pre and post treatment showed increase of the of pediatric scale score (41.80 ± 1.32 versus 36.53 ± 3.07 , $p=0.0001$) while insignificance in control group (36.07 ± 2.91 versus 36.53 ± 2.72 , $p=0.0558$). The study group pre and post treatment showed decrease of the spasticity degree (1.47 ± 0.52 versus 2.40 ± 0.63 , $p=0.0001$) while worthless regarding control group (1.53 ± 0.52 versus 1.60 ± 0.51 , $p=0.3343$) and the study group pre and post treatment showed increase of stride time level (11.07 ± 1.91 versus 12.93 ± 2.25 , $p=0.0002$) while insignificance regarding control group (12.27 ± 1.58 versus 12.47 ± 1.55 , $p=0.0824$).

Utricle and saccule stimulation occurs by placing galvanic stimulation on mastoid processes in which cathode on one side and anode on another side which lead to sway on the anodal side. The perception tilt sway occur toward the paralyzed side so the anode should be located on the mastoid process of the paralyzed side because it decreases the firing rates in vestibular afferent of anodal current this will cause

shifting in subject perception sway(tilt) in a direction opposite to that turned in walking^{13,31}

When a patient walks in a well-learned place he will have a pre-programmed strategy and neural motor circuits so when the patient makes a fast walking there is decrease in sway as a result of vestibular signals is less vital in fast walking as it depends on pre-programmed motor strategy and less of vestibular input while slow walking depends mainly on vestibular input so the sway in vestibular impairment is more in slowly walking than fast walking³². Patients with vestibular impairment make sway laterally, decrease walking speed and increase head movement as a compensatory mechanisms³³. Patients with unilateral vestibular impairment suffer from sway toward affected side³⁴.

The response of GVS is low when the patient is in standing but has a great effect during walking. This is an indicator that vestibular apparatus is very vital during walking more than during standing³⁵⁻⁴⁰ GVS could stimulate the semicircular canal which evoked by angular acceleration and head velocity also could stimulate the static utricle and saccule which evoked by linear acceleration and head tilt⁴¹

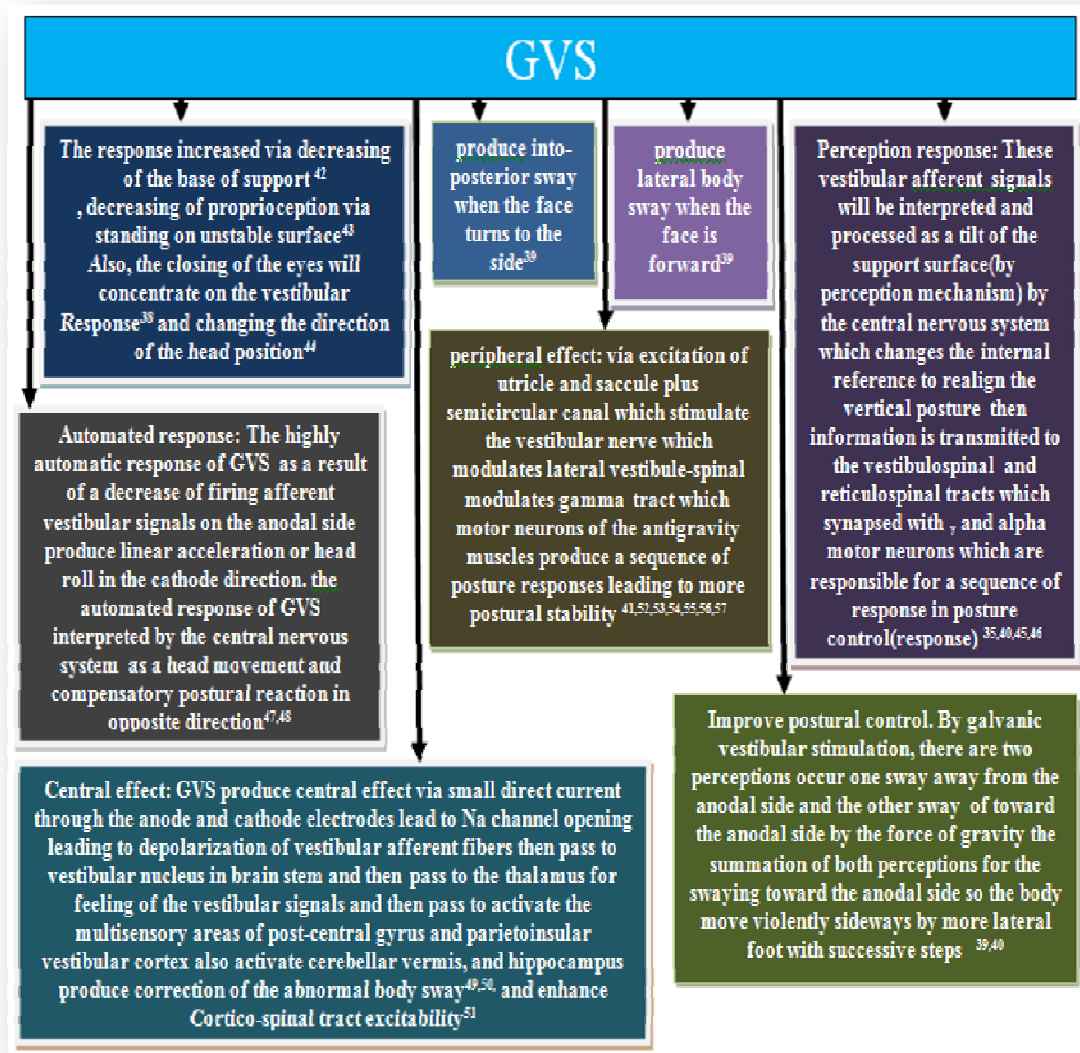


Figure 1. Underlying mechanisms of vestibular galvanic electric stimulation

The static and kinetic labyrinthine provide the CNS with successive sensory input about the linear and rotatory acceleration of the head which activates postural control during head movement via vestibulospinal and reticulospinal tracts⁵⁸

GVS is an electric stimulation passed through application over mastoids producing modulation of the vestibular hair cells and their afferent activity^{12,59}. GVS could decrease the abnormalities in walking performance especially in slow walking

because the vestibular apparatus has a great role in postural stability in slow walking than in fast walking^{60,61,62,63,64}

Because the vestibular apparatus is a nonlinear fundamentally so the numbers of the neural network units increase the spread of stimulation producing large correct neural response due to more complicated neural network were involved in dynamic balance than in static balance which leads to improvement of stride length and time and walking velocity^{65,66}

The vestibular disorder clinical picture includes static symptoms which include vestibular nystagmus, head tilting, and body as a vestibulospinal sign, vertigo, perception sway and autonomic manifestations(nausea and vomiting) .it needs short time for compensations to occur. Dynamic symptoms include impaired postural control and VOR deficits. It is poorly compensated and take a long of time⁶⁷. The vestibular restoration therapy is aiming for formation new learned dynamic strategies that can adjust posture during walking to reach the best performance of daily activities. The vestibule-plasticity depends on changing of the traditional neural circuits to well-developed strategies. The interplay between the brain plasticity and vestibule-plasticity in developing re-synaptic connection is the way for reaching the optimum dynamic balance control⁶⁸. The molecular and cellular responses of the CNS due to feedback input and feedforward command as a result of physiotherapy training which produces increasing of neurotrophins, neurogenesis and new motor strategies which improve CNS plasticity⁶⁹.

Mechanisms of vestibular recovery

Restoration: mean recovery to the original functional movement as peripheral sensory hair cells can be regenerated due to the presence of intrinsic abilities of peripheral vestibular synapses to reorganized. The vestibular plasticity has actually occurred in peripheral vestibular sensory functions because the altered sensory pathway is the way to restore the vestibular function via processing of new strategies^{70,71}

Adaptation mechanisms: include sensory substitution mechanism and behavior substitution mechanisms which are the bases of motor learning .it is a qualitative variation mechanism which needs for active participation in vestibular rehabilitation via dynamic interactions with the environment. In this vital mechanism, the skill did not restore but changed to new motor strategies^{72,73}

Habituation mechanism is the gradual decrease of the response as a result of repeated nonnoxious stimulus. It is a quantitative mechanism that not needs for active participation. It is occurred as a result of Ca^{++} channel blocked at the pre-synaptic levels which lead to decreasing of the excitatory post-synaptic potentials which modify the synaptic activity^{74,75}.

Figure 2. Underlying mechanisms of vestibular-plasticity mechanisms.

The desensitization practices in vestibular restoration therapy is aiming for learning acquisition process to deal with difficult circumstances and responses could be used in vertigo treatment^{74,76,77,78} Vestibular restoration therapy should concentrate on adaptation mechanism for gaining the dynamic vestibular skill sensory substitution play a vital role in recovery of vestibular impairment by increasing the sensory feedback during close and open eyes, disturbance stimulus through different positions and manipulating the surface(unstable-rough-smooth-rubbery), upside down training. proprioceptive training through static weight bearing and dynamic approximation plus a sense of weights to gain improvement of postural sway^{73 79,80,81}

Limitation of the study

-This study had specific limitations that can be concerned in the future research. Selection of larger groups of different forms and types of cerebral palsy children as(spastic diplegia and quadriplegia- dyskinesia-ataxia-mixed type of CP) are required to produce a foundation and principle when dealing with galvanic vestibular stimulation in pediatric rehabilitation.

- All of the hemiplegic CP children in this present study explore a sensory discomfort during application of galvanic vestibular stimulation.

-The GVS parameters in the present study were selected at the sensory threshold stimulus with the intensity of 0.5 mA intensity with long latency more than 200 ms for 30 minutes. Other current parameters and electrodes placement will be needed in further research to locate the effect of long run GVS on different cases in pediatric rehabilitation.

Conclusion:

The combined vestibular training program and trans-mastoidal vestibular galvanic stimulation are suggested in improving walking performance and upright postural stability in a static and dynamic situation. So this selective physiotherapy approach may be used as a strong choice for improving walking and balance abilities in hemiplegic C.P children.

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