HUMAN MOVEMENT
2017; 18(4): 3–9

GAIT ADAPTATIONS AFTER VESTIBULAR STIMULATION IN CHILDREN WITH CONGENITAL VISUAL IMPAIRMENTS: A COMPARATIVE STUDY

original paper
doi: 10.1515/humo-2017-0034

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ABSTRACT
Purpose. The study is based on the hypothesis that individuals with congenital total or partial loss of vision develop more effective gait adjustments compared with those who are sighted, after stimulation of the vestibular system. Therefore, they are able to manage their motor control better. The aim was to investigate the way individuals with congenital total or partial vision loss adjust their gait following vestibular stimulation, compared with sighted blindfolded individuals.
Methods. The total of 10 children with congenital visual impairments constituted the experimental group and 10 children with normal vision (blindfolded with special mask) formed the control group. We performed gait analysis (forward and backward gait direction) with a three-dimensional gait analysis system. The walking speed (m/s) of each group, before and after the vestibular stimulation, during forward and backward gait, was analysed.
Results. The average walking speed of the children in the experimental group, statistically, revealed no significant differences before and after the vestibular stimulation. Conversely, in the control group, statistically significant differences in the mean walking speed before and after the vestibular system stimulation were found.
Conclusions. Children with congenital total or partial blindness may adapt their gait strategy more adequately, after vestibular stimulation, during forward and backward gait, as compared with sighted blindfolded children. Consequently, the first group is in the position to manage their motor control more sufficiently.
Key words: children, vestibular system, gait, stimulation, blindness, motor control

Introduction

The successful maintenance of postural control during standing and gait requires the incorporation of three main sensory systems: the visual, vestibular, and somatosensory system [1]. The postural control system requires information from the visual, vestibular, and proprioceptive systems; the lack or inadequacy of the visual input affects the ability to maintain balance [2–3]. Additionally, it modifies normal gait patterns [4–7] and balance [8–10]. In order to compensate for the defective gait, further postural abnormalities develop, creating a vicious circle [11]. Research has shown that children and adolescents with visual impairments perform more deficiently in static and dynamic activities than their peers without visual impairments [5, 12–17].

Blind individuals display continuous musculoskeletal deformities [18]. Other postural compensations found in blind people include flat feet (planovalgus feet) with fingers pointing outward and a wide base of support, hip and knee contracture, spinal kyphosis, shoulder anteversion, position of the head in anterior protrusion, and poor development of the lower limbs muscles [4, 19]. At stillness, they are found to keep their fingers extended, which demonstrates anxiety [19].

Gait analysis on flat ground among individuals with deficits of the peripheral visual system (both total and partial blindness) was performed, showing that the experimental group (visual impairments) exhibited shorter stride length, retrusion of the trunk, and greater plantar flexion of the ankle after the initial contact of the foot with the ground, compared with the control group (normal vision). In parallel, no difference was observed in the preferred walking speed. However, when the control group was blindfolded, they demonstrated reduced walking speed and increased plantar flexion of the ankle at the initial contact of the foot with the ground, in relation to normal vision conditions [20].

In an fMRI study, blind subjects used different strategies for locomotion than those with normal vision. The

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Received: July 13, 2017
Accepted for publication: August 31, 2017

Citation: Tsaklis P, Alexandros Zorzos S, Mertyri D. Gait adaptations after vestibular stimulation in children with congenital visual impairments: a comparative study. Hum Mov. 2017;18(4):3–9; doi: 10.1515/humo-2017-0034.

latter suppress vestibular and somatosensory activity during the imagined locomotion, more intensely during running and to a lesser extent during walking. On the other hand, individuals with congenital total loss of vision activate the vestibular cortical regions and exhibit increased activity in the somatosensory cortex during imagined locomotion, compared with those who are sighted. They appear to be based on vestibular and somatosensory feedback for locomotion control [21].

The purpose of this comparative study was to investigate the manner in which children with congenital total or partial blindness adjusted their gait strategy subsequent to vestibular stimulation, compared with sighted children. The research hypothesis was based on the fact that individuals with congenital visual impairments developed more effective adjustments in their gait than those who are sighted, following vestibular stimulation. Therefore, they are able to manage their motor control more adequately.

The above hypothesis is enhanced as blind individuals have superior sensory abilities in non-visual functions. In fact, they usually achieve better results than sighted individuals in a wide range of auditory, tactile, and olfactory processes [22–26].

Material and methods

Study design

A comparative study was conducted between two groups of children; the first group included individuals with congenital visual impairments (total or partial blindness), while the second group involved sighted individuals. Since the study concerned children, a customized written acquiescence and consent of their parents or guardians was provided; also, they could be informed about the results of the study. The study was approved by the Research Ethics Committee at the Alexander Technological Educational Institute of Thessaloniki.

Subjects

The present study involved 10 children (7 males and 3 females) with visual impairments, aged 7–12 years (mean age, 10.1 years), and 10 children (7 males and 3 females) with normal vision, aged 7–12 years (mean age, 9.6 years). The first group formed the experimental group, while the second one constituted the control group.

The experimental group consisted of children with congenital impairments of the peripheral visual system, listed in Table 1. The group of individuals with visual impairments is the most informative as for the accurate comprehension of the developmental processes since they represent the lowest probability of confusion between the variables [27]. The central processing of visual information is not affected in this population, so it is considerably likely that the observed differences in the spatiotemporal parameters of the gait may be only related to the absence of visual information. In the study, only the impairments affecting the peripheral visual system were included.

Table 1. Peripheral visual impairments of the children in the experimental group

Cone-rod dystrophy
Congenital achromatopsia
Albinism
Retinopathy of prematurity
Leber congenital amaurosis (dystrophy of retina)
Stargardt disease (inherited macular degeneration)
PAX6 syndrome

In the International Classification of Diseases (ICD-10th Revision), low vision is defined as visual acuity ≥ 1/20 or visual acuity < 3/10 or visual field < 20° in the best eye with the best possible correction, while total blindness is determined as visual acuity < 1/20 or visual field < 10° in the best eye with the best possible correction [28]. Among the 10 children in the experimental group, 7 had total vision loss without light perception, while 3 suffered from partial vision loss.

The selection criteria for the experimental group concerned total or partial blindness, peripheral visual impairments, and age between 7 and 12 years. In turn, the exclusion criteria involved recent injuries to the lower limbs, as well as musculoskeletal and neurological diseases.

Instrument and procedure

The three-dimensional gait analysis was conducted in the Laboratory of Biomechanics and Ergonomics of the Department of Physiotherapy, at the Alexander Technological Educational Institute of Thessaloniki, Greece.

More extensively, a motion detection system (Vicon-Nexus 1.8.5) with six infrared emission cameras (100 Hz capture speed) was used for detecting the reflective markers and calculating the kinematic characteristics of gait. The data were further analysed with the Vicon Polygon 3.5.1 software.

After the selection and recruitment of the sample, a meeting for each individual was conducted at the gait analysis laboratory. Each child was accompanied by their parents or guardians. Then the procedure was thoroughly described to the parents and the children who participated in the study. The demographic and anthropometric characteristics of each individual were collected (Table 2).

Afterwards, 22 reflective markers were placed on each child' body in accordance with the Plug-In-Gait® model (Figure 1) [29].

Table 2. Demographic and anthropometric data of the experimental and control group

Participant	Gender	Age (years)	Weight (kg)	Height (m)
Experimental group				
1	m	12	29	1.33
2	m	12	51	1.42
3	f	11	51	1.54
4	m	12	49	1.41
5	f	11	49	1.49
6	m	8	41	1.33
7	m	7	18	1.11
8	m	9	43	1.37
9	f	10	45	1.45
10	m	9	42	1.38
Control group				
1	m	12	67	1.60
2	f	8	34	1.28
3	m	10	44	1.38
4	f	7	19	1.12
5	m	10	52	1.50
6	m	8	25	1.33
7	m	11	48	1.49
8	f	9	44	1.36
9	m	10	45	1.43
10	m	11	47	1.46

m – male, f – female

Initially, a static measurement was performed in order to model each subject in relation to the three-dimensional space (Figure 2).

The variable of investigation was the walking speed (m/s), resulting from the forward displacement of the left anterior suprailiac (LASI) reflective marker, in accordance with the Vicon Plug-In-Gait® model [29].

Subsequently, we asked each individual to walk barefoot at a self-selected speed with clear verbal commands before starting the gait attempt (e.g. 'walk forward' or 'walk backward'), hierarchically and strictly without the intervention of corrective verbal commands during the effort. As compared with the forward walking (FW), the backward walking (BW) pattern was selected because the leg kinematics in BW is essentially that of FW in reverse. Furthermore, the upper and lower limb kinematics of FW correlates highly with BW kinematics in children, which appears to be consistent with the proposal that the control of FW and BW may be similar.

It should ne noted that all individuals from both groups were familiarized with the laboratory space, and had applied walking trials before the recording – especially the sighted children after the blindfolding with the mask, for at least 3 minutes in order to feel safe and comfortable without vision.

Figure 1. Placement of 22 reflective markers at specific points of the pelvis and lower limbs, in accordance with the Plug-In-Gait® model

Figure 2. Static measurement of each individual

For both the experimental and the control group individuals, vestibular stimulation was performed in the following manner. Starting in quiet bipedal stance, with arms relaxed along the body, head facing straightforward, the children began to move their heads in a fluid circular motion: chin on chest, then left ear on left shoulder. Then they moved their heads to a backward (looking up) position, right ear on right shoulder, finally returning chin to chest. This circular movement was repeated 10 times, one set clockwise, one set anticlockwise, without any interval between the sets, with the speed selected by a metronome at 30 b/min (2 s/head circle) [30].

The experimental and control group protocol included:

1. Task, forward gait prior to vestibular stimulation.
2. Vestibular stimulation.
3. Task, forward gait immediately after vestibular stimulation.
4. Interval 2–3 minutes and repeat steps 1–3.
5. Task, backward gait prior to vestibular stimulation.

6. Vestibular stimulation.

7. Task, backward gait, immediately after vestibular stimulation.

8. Interval 2–3 minutes and repeat steps 5–7.

Two successful walking trials forward and two trials backward for each task were collected and the best walking speed value of the two was marked.

Statistical analysis

For statistical analysis, the SPSS®, version 21.0 for Windows, was used. A check for normality of the populations with the Shapiro-Wilk test was applied because the samples were less than 50 observations. Both teams had the significance value of > 0.05, thus it was accepted that both came from normal populations. The t-test was performed in order to find the differences in the mean values of the two populations in paired observations (paired t-test). The significance level was set at $p < 0.05$. The mean walking speed (m/s) was measured in 4 pairs of observations:

– Pair 1: forward gait of children with visual impairments – forward gait of the same individuals after vestibular stimulation.

– Pair 2: backward gait of children with visual impairments – backward gait of the same individuals after vestibular stimulation.

– Pair 3: forward gait of sighted blindfolded children – forward gait of the same individuals after vestibular stimulation.

– Pair 4: backward gait of sighted blindfolded children – backward gait of the same individuals following vestibular stimulation.

Ethical approval

The research related to human use has been complied with all the relevant national regulations, institutional policies and in accordance the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

Results

The 10 children from each group successfully performed all the procedures required for the walking analysis. Neither one complained, felt discomfort, or requested to stop the process. The box plots in Figures 3–6 depict the variation of the gait speed values, with the bottom and top representing the first and third quartiles, respectively, and the band inside standing for the median value.

The mean speed of the forward gait performed by the children with visual impairments prior to vestibular stimulation was 1.11 m/s and afterwards 1.07 m/s. During the backward gait, the children with visual impairments walked with 0.79 m/s speed prior to vestibular stimulation and with 0.76 m/s afterwards.

The mean speed of the forward gait performed by the sighted blindfolded children prior to vestibular stimulation was 1.32 m/s and afterwards 0.60 m/s. During the backward gait, the sighted blindfolded children walked with 1.03 m/s speed prior to vestibular stimulation and with 0.5 m/s afterwards.

The statistical analysis revealed that the mean walking speed was not significantly greater in the individuals with visual impairments prior to, in comparison with after vestibular stimulation, during forward gait (p = 0.786). Similarly, the mean walking speed was not significantly greater in the individuals with visual impairments prior to, in comparison with after vestibular stimulation, during backward gait (p = 0.322) (Table 3).

On the other hand, the mean walking speed turned out significantly greater in the sighted blindfolded individuals prior to, in comparison with after vestibular stimulation, during forward gait (p = 0.001). Similarly, the mean walking speed was significantly greater in the sighted blindfolded individuals prior to, in comparison with after vestibular stimulation, during backward gait (p = 0.001) (Table 3).

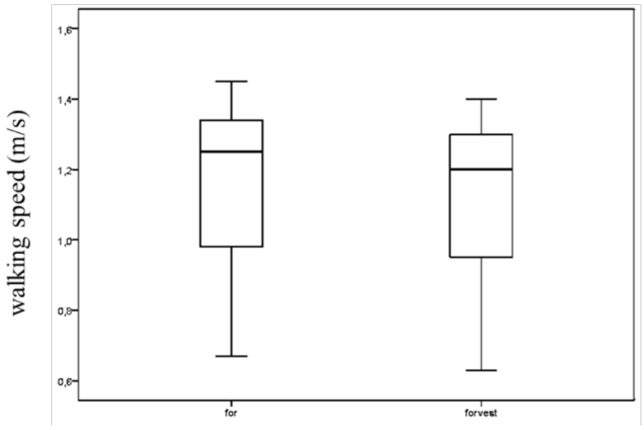

Figure 3. Forward gait speed of children with visual impairments before (for) and after (forvest) vestibular stimulation (no significant difference)

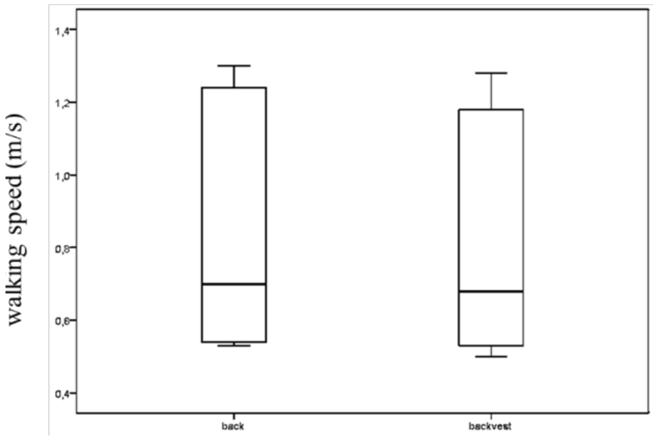

Figure 4. Backward gait speed of children with visual impairments before (back) and after (backvest) vestibular stimulation (no significant difference)

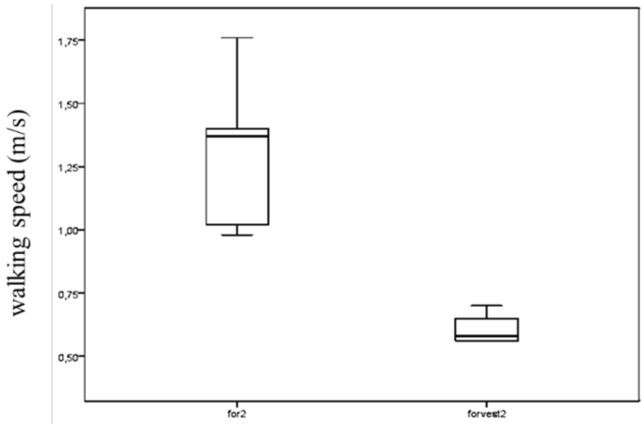

Figure 5. Forward gait speed of sighted blindfolded children before (for2) and after (forvest2) vestibular stimulation (p = 0.001)

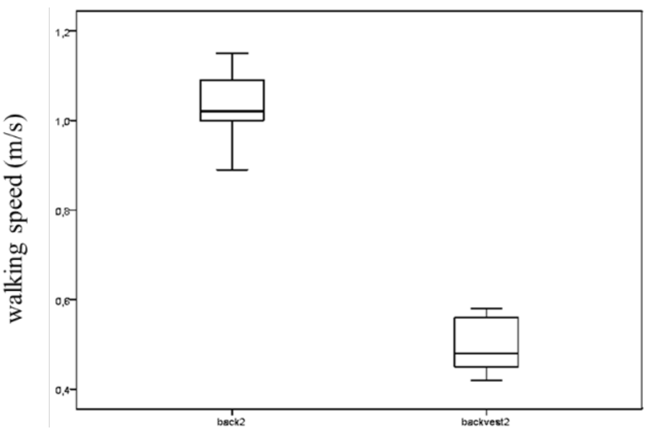

Figure 6. Backward gait speed of sighted blindfolded children before (back2) and after (backvest2) vestibular stimulation (p = 0.001)

Table 3. Paired t-test results

Paired samples test		Mean	*SD*	Significance (2-tailed)
Pair 1	(blind) forward forward VS	0.04000	0.01247	0.786
Pair 2	(blind) backward backward VS	0.03000	0.01491	0.322
Pair 3	(sighted) forward forward VS	0.71700	0.28956	0.001
Pair 4	(sighted) backward backward VS	0.53400	0.08208	0.001

VS – vestibular stimulation

Discussion

The results of the study support our initial hypothesis that individuals with congenital visual impairments develop more effective adjustments in their gait than those who are sighted, following vestibular stimulation.

The above results prove that children with congenital total or partial blindness due to impairments of the peripheral visual system may adapt their gait, in particular their gait velocity, more effectively following vestibular stimulation, during forward and backward gait, in contrast to sighted children. This may result from the fact that they are based on vestibular and somatosensory feedback for movement control [21], and they are also in the position to compensate the absence of visual input with their remaining senses [31].

As we blindfolded the sighted children with the use of a special mask and removed the possibility of visual input, statistically they represented a significantly higher walking speed, prior to vestibular stimulation, during forward and backward gait. Possibly, to compensate for the instability due to the vision removal, the participants adopted a cautious gait pattern. This gait pattern is used likely because information from the proprioceptors and vestibular organs cannot sufficiently substitute the visual system [32]. Thus, children with normal vision cannot adequately manage their motor control after the removal of visual information and stimulation of the vestibular system. This could be of clinical importance and use, especially when the treatment goal for particular cases is the balance and agility enhancement.

However, this study presents some limitations. First of all, the sample was relatively small (n = 20, 10 individuals in the experimental and 10 in the control group) as a result of the rigorous inclusion criteria for participation in the study. More analytically, visual impairments should have been caused by a problem at the level of the lens, cornea, retina, or optic nerve. As there is improvement in health care, the incidence of these ocular problems is further decreasing.

Therefore, we chose to exclude individuals with cerebral visual impairments to make sure that the observed differences of the gait were due to the absence of visual stimulus and were not affected by cerebral processing problems. For similar reasons, subjects with neurological problems (e.g. cerebral palsy or visual impairments) were excluded from the study. Because of this restrictive criterion for selection, we are pretty sure that the observed differences in gait are in fact adjustments resulting from the lack of visual information.

Another limitation is that the gait analysis was performed in an experimental environment (set environment) that considerably differs from the environment of everyday life, where obstacles, turns, and steps are frequent. This limits the generalization of our results. On the other hand, this shows that even in a set and secure environment, vision is important for the control of locomotion.

Also, among the limitations is the fact that the vision in the control group was completely eliminated by blindfolding with a special mask, while in the experimental group some individuals (3 out of 10) still exhibited some minimal residual visual acuity. This may be one of the causes for the biggest changes in the children's gait pattern in the control group, when we blindfolded them and removed their visual information, as compared with those in the experimental group, who had partial blindness.

Finally, it is important to note that the research literature in respect to the gait following vestibular stimulation in children with congenital total or partial loss of vision is deficient.

Conclusions

In the current study, the children with congenital total or partial vision loss utilized their motor mechanisms and adapted their gait more adequately than those who were sighted and had been blindfolded, following stimulation of the vestibular system, during forward and backward gait. However, there is a strong need for more comparative studies with a larger sample of children and additional dynamic activities.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

Authors state no conflict of interest.

Acknowledgements

The authors would like to thank the instructor of mobility, orientation, and daily skills of individuals with total or partial loss of vision, Mrs Lina Kalle, for her support in the recruitment of the sample, both of the children with visual impairments and those with normal vision.

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