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Effect of the Modulation of Optic Flow Speed on Gait Parameters in Children with Hemiplegic Cerebral Palsy

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Abstract. [Purpose] We investigated the effects of modulation of the optic flow speed on gait parameters in children with hemiplegic cerebral palsy. [Methods] We examined 10 children with hemiplegic cerebral palsy. The children underwent gait analysis under 3 different conditions of optic flow speed: slow, normal, and fast optic flow speed. The children walked across the walkway of a GAITRite system, while watching a virtual reality screen, and walking velocity, cadence, stride length, step length, single support time, and double support time were recorded. [Results] Compared with the other applied flow speed conditions, the fast optic flow speed (2 times the normal speed) significantly increased walking velocity, cadence, normalized step length, base of support, and single support cycle of both the paretic and non-paretic lower limbs. Moreover, compared with the other applied flow speed conditions, the slow optic flow speed (0.25 times the normal speed) yielded a significantly decreased walking velocity, cadence, normalized step length, base of support, and single support cycle for both the paretic and non-paretic lower limbs. [Conclusion] The gait parameters of children with hemiplegic cerebral palsy are altered by modulation of the optic flow speed. Thus, we believe that gait training involving modulation of the optic flow speed is feasible and suitable for resolving abnormal gait patterns in children with hemiplegic cerebral palsy.
Key words: Optic flow, Gait parameter, Hemiplegic cerebral palsy

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INTRODUCTION

Cerebral palsy is a nonprogressive disorder that occurs during early brain development and presents with abnormal movement and posture[1, 2)]. Previous studies indicated that 90% of patients with cerebral palsy exhibit impaired gait patterns due to excessive muscle weakness, altered joint kinetics, and diminished postural reactions[3)]. The impairments cause abnormal gait, including developmental disability in the upper and lower extermities[4)], a wide base of support, decreased step and stride lengths, reduced time in single stance, and a slower walking velocity[5)]. Therefore, a common goal of rehabilitation in children with cerebral palsy is the recovery of functional gait[6, 7)].

Certain aspects of gait control in humans are generated by integration of visual, proprioceptive, and vestibular information[8)]. Visual information input is essential for detecting and identifying sensory information from the surrounding environment, thus enabling appropriate spatiotemporal anticipation, before initiating and completing movement[9)]. Therefore, alteration of visual information input importantly influences gait velocity in humans[10)]. Hence, many studies involving rehabilitation of patients demonstrating a hemiplegic gait pattern have employed visual information techniques such as visual feedback therapy and virtual reality training methods[11–13)].

Yang et al. investigated the effects of virtual reality treadmill training on functional gait in hemiplegic stroke patients, and the results of this training appeared to demonstrate improvement of gait function and patient mobility[13)]. Baram et al. reported that visual feedback improved walking speed and stride length in patients with hemiplegic cerebral palsy[14)].

Optic flow is the pattern of motion perceived at the retina, which specifies the direction of locomotion[15)] and provides vital feedback concerning patient regulation of walking velocity[16)]. Prokop et al. reported that modulation of optic flow resulted in changes in gait parameters such as gait velocity, cadence, and stride length in human subjects[17)]. Lamontegne et al. reported that a fast optic flow speed resulted in increased walking velocity and cadence in hemiplegic stroke patients[18)]. Moreover, Kang et al. reported that treadmill training, along with modulation of optic flow, improved gait velocity in hemiplegic patients following a stroke[8)].

Several such studies concerning the effects of optic flow alterations on gait parameters are found in the literature. However, the majority of these studies assessed both hemiplegic stroke patients and healthy adults. Therefore, in the

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present study, we examined the alterations in gait parameters due to modulation of the optic flow speed specifically in patients with hemiplegic cerebral palsy.

SUBJECTS AND METHODS

In the present study, we examined 10 children with hemiplegic cerebral palsy who visited the Community Rehabilitation Welfare Center, Korea. The general characteristics of the children are described in Table 1. All subjects and guardians signed an informed consent form after they understood the contents of the study. The inclusion criteria were as follows: a current diagnosis of hemiplegic cerebral palsy, ability to walk unassisted or with only minimal assistance for more than 10 m, patient motor function consistent with level I and II according to the Gross Motor Function Classification System (GMFCS), and no visual deficit. The study was approved by the human research ethics committee of all the participating institutions.

This study design is cross-sectional. All subjects were evaluated for alteration of gait parameters using a GAITRite system. Each subject was evaluated during application of optic flow speeds at 3 different levels, as follows: slow (0.25 times the normal speed), normal, and fast (2 times the normal speed). The visual information was projected on a screen via a connected notebook with virtual reality software, which mimicked walking in a park.

Patient procedural parameters were established as follows: First, all subjects walked at a self-selected speed on the GAITRite system, without visual program input information. Second, prior to recording flow speed and gait effects, all subjects adapted their gait to the visual information during a 10-min trial of the 3 levels of optic flow speed, which were randomly applied. Third, the subjects who had watched the screen playing the visual information with one of the 3 optic flow speeds and a self-selected gait speed, walked across the walkway of the GAITRite system. The subjects walked 5 times at each optic flow speed, and the data was reduced to a mean value for each subject examined. A 3-min rest period was allowed between each intervention, to minimize the effects of muscular fatigue. Any subject who required assistance was provided minimal assistance by a therapist who was not informed about the purpose of the subject's activity or the purpose of the study.

The GAITRite System (CIR Systems Inc., Sparta, NJ, USA) recorded the spatiotemporal gait data. This device has an electronic walkway measuring approximately 700 × 90 cm, with pressure sensors placed in a horizontal grid along the walking surface; the device is connected via an interface cable to a notebook running the MS Windows XP operating system. The recording area of the device generally measures 61 cm in width and 732 cm in length. Sensors are maintained at a distance of 1.27 cm from each other (totaling 27,648 sensors), and a recording frequency of 80 Hz is used with temporal resolutions of 11 ms. The GAITRite Gold, Version 3.2b, software was used for spatiotemporal data analysis. The procedure for evaluation using the GAITRite system was as follows: each subject stood in front of the mat, and when cued by the evaluator, the subject walked onto and along the mat at a self-selected walking speed. The collected data consisted of temporal gait characteristics such as velocity, cadence, single support time, double support time, and spatial gait characteristics including step length and stride length. The measurement reliability of this system is r = 0.90, and the ICC is 0.96[10, 19].

SPSS version 12.0 was used to calculate the mean and standard deviations. Repeated measure ANOVA was used to compare spatiotemporal gait parameters for each optic flow speed. All data were calculated at a significance value of $p< 0.05$.

Table 1. General characteristics of the children with hemiplegic cerebral palsy

Subject	Gender	Age (years, months)	Height (cm)	Paretic limb	GMFCS level
S1	Male	5, 5	109	R	I
S2	Male	6, 1	117	R	I
S3	Female	4, 10	84	L	I
S4	Male	5, 8	103	R	II
S5	Female	4, 6	95	R	I
S6	Male	5, 2	112	R	I
S7	Male	4, 1	96	L	I
S8	Male	6, 1	124	L	I
S9	Male	3, 9	97	R	I
S10	Female	4, 2	99	R	I

R, right; L, left; GMFCS, Gross Motor Function Classification System

RESULTS

The fast optic flow speed (2 times the normal speed) significantly increased walking velocity, cadence, normalized step length, base of support, and single support cycle of both the paretic and non-paretic lower limbs as compared with the other flow conditions applied ($p> 0.05$). Moreover, the slow optic flow speed (0.25 times the normal speed) induced significantly decreased walking velocity, cadence, normalized step length, base of support, and single support cycle of both the paretic and non-paretic lower limbs as compared with the other flow speed conditions applied ($p> 0.05$) (Table 2).

DISCUSSION

This study compared the alteration in spatiotemporal gait parameters according to the application of slow, normal, and fast optic flow speeds in patients with hemiplegic cerebral palsy.

Optic flow induced an immediate change in gait speed of the subjects under study[20]. After occurrence of an incongruity between alteration of the optic flow speed and the resulting proprioceptive information observed in the lower extremity, the subjects decreased the incongruity by altering movement in the lower extremity[8, 17–18]. Konczak et al. reported that an increased optic flow speed in healthy adults induced an increase in walking velocity more quickly than

Table 2. Comparison of gait parameter among the different optic flow speeds

Parameters		Slow OF	Normal OF	Fast OF
Velocity[abc] (cm/sec)		48.7±2.3	56.9±2.9	69.3±2.8
Cadence[abc] (step/min)		109.2±2.5	122.8±2.3	134.4±2.5
Normalized step length (step length / leg length)	Affected side[abc]	0.7±0.1	0.7±0.1	0.8±0.2
	Non-affected side[abc]	0.7±0.1	0.7±0.1	0.8±0.1
Base of support (cm)	Affected side [abc]	12.5±0.3	11.4±0.5	10.1±0.7
	Non-affected side[abc]	13.2±0.3	12.0±0.4	9.4±0.4
Single support (% gait cycle)	Affected side[abc]	32.7±0.4	35.2±0.4	37.3±0.3
	Non-affected side[abc]	36.1±1.1	38.2±1.3	40.2±1.6

All variables are presented as mean±standard deviation values. OF, optic flow.
[a]Statistically significant difference between slow OF and normal OF ($p<0.05$).
[b]Statistically significant difference between slow OF and fast OF ($p<0.05$).
[c]Statistically significant difference between normal OF and fast OF ($p<0.05$).

that induced by a reduced optic flow[21]. Prokop et al. reported that alterations of optic flow speed in healthy adults resulted in modulation of stride length and walking velocity because optic flow interpretation by the brain played a major role in the regular gait pattern and gait control[17]. Therefore, changes in the gait patterns of healthy adults were induced by altering the optic flow speed.

In previous studies involving subjects with several spatiotemporal orientation types, Schubert et al. reported that patients with Parkinson's disease, tested through application of various optic flow speeds ranging from 1 to 3 times the normal speed, changed their gait speed and cadence more quickly than elderly adults and healthy adults. This phenomenon was attributed to the fact that patients with Parkinson's disease experience excessive reliance on visual feedback due to the impairment of proprioceptive guidance during voluntary movement and damage noted as sensory scaling associated with altered kinesthesia[22]. Lamontegne et al. reported that poststroke hemiplegic patients demonstrated altered gait speed and cadence when influenced by large differences in optic flow speed[18]. Thus, changes in gait control in patients with Parkinson's disease and patients with hemiplegic stroke were both influenced by alterations in optic flow speed.

This study indicated that the fast optic flow speed in hemiplegic cerebral palsy subjects, generated altered temporal parameters in gait speed, cadence, single support time of the affected and non-affected side, and double support time of the affected and non-affected side more quickly than application of the slow optic flow speed, self-selected gait speed, or normal optic flow speed. Moreover, the fast optic flow speed induced alterations of spatial parameters in stride length in the hemiplegic cerebral palsy subjects, on the affected and non-affected sides as well as step length on the affected and non-affected sides, for an extended period of time when compared with the alterations produced by all the other applied optic flow speeds. In a previous study, alteration of optic flow speeds in hemiplegic stroke patients resulted in gait alterations similar to those found in hemiplegic cerebral palsy subjects. Kang et al. reported that the application of a fast optic flow speed in hemiplegic stroke patients induced spatial and temporal parameters more quickly than the application of slow and normal optic flow speeds. The most prominently observed deficits in patients with hemiplegic cerebral palsy were noted in gait velocity, decreased step and stride lengths, and reduced time in single stance, although self-selected gait was not affected[5]. Therefore, a rehabilitation program including alterations of the optic flow speed in children with hemiplegic cerebral palsy may improve gait parameters.

Moreover, alterations of gait parameters, as a result of alterations of the optic flow speed, in children with hemiplegic cerebral palsy were found to be similar to those produced in hemiplegic stroke patients. Such gait alterations in both patient groups are generated by changes in lower limb response patterns due to the patient's intention to decrease the incongruity between proprioceptive information of the lower limbs and the optic flow speed.

Limitations of the present this study include the relatively small group of eligible subjects available and the absence of control group data. Therefore, further similar studies involving a larger subject population and a non-affected control group are needed. Furthermore, studies documenting the effects of a rehabilitation program using variable optic flow speeds in the treatment of children with hemiplegic cerebral palsy, are considered to be a necessary prerequisite to the addition of variable optic flow movement therapies in rehabilitation hospitals.

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