Gait improvement in patients with cerebral palsy by visual and auditory feedback

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***Abstract*—Visual and auditory feedback cues have been shown to improve gait and balance in patients with movement disorders, such as Parkinson's disease and multiple sclerosis. Subsequently, closed-loop virtual reality was used to enhance the gait improvement effect of such cues. Objectives: To study the effects of gait training with visual and auditory feedback cues on the walking abilities of patients with gait disorders due to cerebral palsy. Methods: Visual and auditory feedback cues were generated by a wearable accelerometry-driven device. Ten randomly selected patients with gait disorders due to cerebral palsy trained with visual feedback cues while ten such patients trained with auditory feedback cues. Baseline performance (walking speed and stride length along a 10m straight track) was measured before device use. Following 20min training with the device, performance without the device was measured again and compared to the baseline performance. Results: For patients training with visual feedback, the average improvement in walking speed was 21.70%+/-36.06% and in stride length 8.72%±9.47%. For patients training with auditory feedback, average improvement in walking speed was 25.43%±28.65% and in stride length 13.58%±13.10%. Conclusion: Visual and auditory feedback cues can improve gait parameters in patients with gait disorders due to cerebral palsy.**

Keywords- Cerebral palsy, motor control, gait disorders, gait rehabilitation, visual feedback, auditory feedback, virtual reality

I. Introduction

Cerebral palsy (CP) is a group of perinatal disorders that present cognitive, motor, and sensory disabilities [1]. Classification is difficult, since each of these disorders and disabilities appears within a wide range of independent severity. The most prominent feature is motor function disorder, associated with a general reduction in EMG activity, selected muscles weakness and afferent inhibition. The motor impairment syndromes seen in CP are secondary to lesions or anomalies in brain development, inhibiting normal automatic and voluntary responses and allowing for the development of dysfunctional ones [1,2,3]. Bilateral and hemiplegic spasticity give rise to difficulties in posture, balance and gait control [2,3,4]. Mobility-related handicaps can considerably limit daily activity, affecting individual well-being and social interaction, and, therefore, have a major impact on overall patient development.

The treatment of Cerebral Palsy involves physical therapy, occupational therapy and sports, targeted at specific conditions. Upper extremity of arm reaching tasks was found to improve in CP patients training in a computer generated environment [5]. EMG feedback was found to be potentially beneficial for gait improvement in patients with CP-related impairment, specifically dynamic equintus deformity [6] and spastic hemiplegia [7]. Training with sensory feedback has been found to improve motor function. Auditory feedback, provided by load-sensitive insole inserted in the hemiparetic side shoe, was found to have a positive effect on gait symmetry in CP [8] but maintenance strategies for this effect are yet to be determined [9]. Balance training with visual feedback was found to improve stance in hemiplegic CP, with a secondary positive effect on gait [10].

Walking over earth-stationary transverse lines has been found to improve gait in patients with Parkinson's disease (PD) [11, 12]. An analytical study of the effects of real world visual cues on the regulation and stabilization of gait [13] has led to the development of a wearable virtual reality (VR) apparatus [14], which incorporates the patient's body motions in the display, so that the visual cues appear to be earth-stationary. Training with this apparatus was found to improve gait in patients with PD [15] and in patients with multiple sclerosis (MS) [16]. Similarly, an auditory feedback device, sounding a clicking sound in response to each step, was found to improve gait in patients with MS [17]. In the present study, we employed these devices to study the effects of training with sensory feedback cues on gait in patients with CP.

II. Methods

A. *Population*

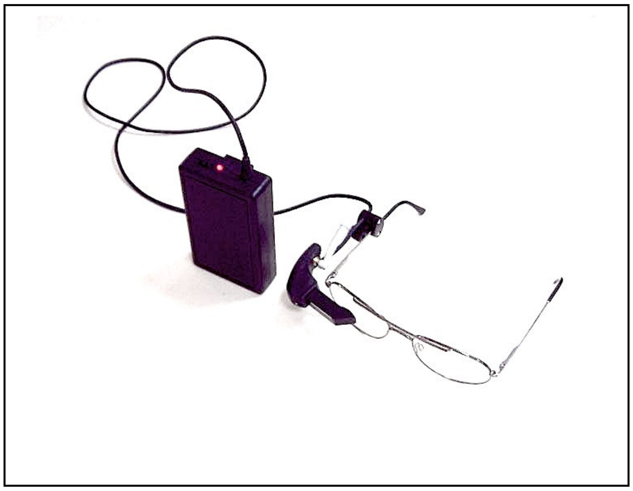
Ten randomly selected patients with gait disturbances due to CP were trained with visual feedback while ten such patients trained with auditory feedback. The study was approved by the Helsinki committee of the Ministry of Health, Israel, and informed consent was obtained from a parent of each of the participants, once the nature of the procedures had been fully explained.

B. *Instruments*

Assessment of patient ambulation was based on walking speed and stride length, calculated directly from measurements of time and number of steps needed to complete a fixed track. Visual cues were generated by a VR apparatus, shown in Fig.

1. The display, attached to the eyeglasses frame, provided the patients with an image of transverse lines, responding

Figure 1: Visual feedback device



dynamically to the patient's own motion, much like a real floor, fixed in space. Auditory feedback cues were generated by a device, shown in Fig. 2, which delivers through earphones a clicking sound in response to each step. Both devices employ an inertial motion sensor and a computing unit enclosed in a belt-mounted box.

C. Procedure

All tests were performed at the ILAN Sports Center for Handicapped Children, Kiryat Haim, Israel, at about the same time in the afternoon. Examination of each patient comprised three stages:

a) Stage 1: Baseline walking speed and stride length without the device were measured. The patient was verbally instructed to walk along a straight track of 10 meters. The time to complete the track and the number of steps were recorded four times and averaged.

b) Stage 2: The device was placed on the patient, and turned on. The patient was instructed to walk four times along the 10-meter track for the purpose of training. Patients training with visual feedback were asked to imagine, while walking, stepping between the virtual transverse lines. Patients training with auditory feedback were asked to maintain, by controling their gait pattern, a rhythmic auditory cue.

c) Stage 3: The device was taken off the patient, who was given a ten-minute break. After the break, the patient was

Figure 2: Auditory feedback device

instructed to walk the 10-meter track without the device. Walking speed and stride length were recorded four times and averaged. The purpose of this stage was to measure the residual short-term therapeutic effect of training with the sensory feedback cue.

III. RESULTS

A. Visual feedback

The test results for patients training with visual feedback are summarized in Table 1. The average improvement in walking speed was 21.70%±36.06%. For participants with baseline walking speed below the median, improvement was considerably higher (35.75%±47.76%) than for participants with baseline walking speed above the median (7.65% ±12.85%). Average improvement in stride length was 8.72%±9.47%. For participants with baseline stride length below the median, improvement was 12.78%±12.13% and for participants with baseline stride length above the median, improvement was 4.67%±3.69%. For participants of age below the median, improvement in walking speed was 9.59%±23.06% while for participants of age above median, improvement was 33.81%±44.96%. For participants of age below the median, improvement in stride length was 9.41%±11.97% while for participants of age above the median, improvement was 8.03%±7.57%.

Table 1: Test results for visual feedback

Patient			Baseline		After training		Percentage change	
name	sex	age	walking speed	stride length	walking speed	stride length	walking speed	stride length
1	F	10	1.285	0.555	1.265	0.571	-1.56%	2.88%
2	M	18	1.419	0.741	1.508	0.769	6.27%	3.78%
3	F	11	1.439	0.606	1.357	0.625	-5.70%	3.14%
4	F	7	0.44	0.328	0.648	0.385	47.27%	17.38%
5	F	26	0.945	0.625	1.052	0.667	10.15%	6.72%
6	F	9	0.401	0.27	0.369	0.263	-7.98%	-2.59%
7	M	6	0.81	0.377	0.939	0.476	15.93%	26.26%
8	F	12	0.687	0.476	1.466	0.571	113.40%	19.96%
9	M	15	1.224	0.588	1.513	0.645	23.61%	9.69%
10	F	19	1.362	0.69	1.575	0.69	15.64%	0.00%

B. Auditory feedback

The test results for patients training with auditory feedback are summarized in Table 2. The average improvement in walking speed was 25.43%±28.65%. For participants with baseline walking speed below the median, improvement was considerably higher (42.79%±32.23%) than for participants with baseline walking speed above the median (8.08% ±7.39%). Average improvement in stride length was 13.58%±13.10%. For participants with baseline stride length below the median, improvement was 13.66%±6.63% and for participants with baseline stride length above the median, improvement was 14.50%±8.44%. For participants of age below the median, improvement in walking speed was 22.83%±18.86% while for participants of age above median, improvement was 28.04%±38.39%. For participants of age below the median, improvement in stride length was 11.95%±6.94% while for participants of age above the median, improvement was 15.21%±18.20%.

IV. DISCUSSION

The results of the present study support the potential role of sensory feedback-based strategies as rehabilitation modalities, and substantiate their specific implementation in efforts to alleviate, improve, and restore mobility in patients with gait disturbances due to CP. For patients using visual feedback, baseline walking speed and stride length were found to be good predictors of improvement, with higher improvement associated with lower baseline performance. For patients using such cues, age was found to be a good predictor of improvement in walking speed, but not in stride length, with significantly higher improvement in walking speed found in patients of older age. For patients using auditory feedback, baseline performance was found to be a good predictor of improvement in walking speed, but not in stride length. Patients of older age showed a somewhat higher improvement than younger patients after training with auditory cues. Future studies may explore the implications of these findings in larger cohort of patients of various clinical sub-categories. An extended- treatment course should be implemented and its effects examined in terms of both the specific functional performance and long-term skill learning. Research that can link sensory feedback-enhanced rehabilitation to long-term learning would have a particular importance in CP, characterized by damage of coordinated inter-neuronal networks leading to associated dysfunction. Sensory feedback–aided motor skill learning may also reveal interventional mechanisms for better resource allocation, functional reorganization, and the role of cerebral plasticity in neurorehabilitation.

Table 2: Test results for auditory feedback

Patient			Baseline		After training		Percentage change	
name	sex	age	walking speed	stride length	walking speed	stride length	walking speed	stride length
1	F	10	1.224	0.513	1.342	0.555	9.64%	8.19%
2	M	18	1.262	0.645	1.259	0.645	6.27%	0.00%
3	M	6	0.851	0.417	1.266	0.5	48.77%	19.90%
4	F	7	0.702	0.333	0.942	0.385	34.19%	15.62%
5	F	26	0.892	0.555	0.914	0.588	2.47%	5.95%
6	F	11	1.171	0.526	1.406	0.588	20.07%	11.79%
7	M	5	0.841	0.351	1.006	0.4	19.62%	13.96%
8	M	5	1.183	0.435	1.206	0.444	1.94%	2.07%
9	F	12	0.543	0.426	0.629	0.476	15.84%	11.74%
10	F	11	0.739	0.455	1.445	0.667	95.53%	46.59%

IV. ACKNOWLEDGEMENT

This work was supported in part by the Roy Matas/Winnipeg Chair in Biomedical Engineering, Technion-Israel Institute of Technology, Haifa, Israel.

REFERENCES

[1] MH Woollacott, P Burtner. Neural and musculoskeletal contribution to the development of stance balance control in typical children and in children with cerebral palsy. Acta paediatr Suppl. 1996 Oct; 416:58-62.

[2] W Berger, J Quintern, V Dietz. Pathiophysiology of gait in children with cerebral palsy. Electroencephalogr Clin Neurophysiol. 1982 May; 53(5):538-48.

[3] W Berger. Characteristics of locomotor control in children with cerebral palsy. Neurosci Biobehav Rev. 1998 Jul: 22(4):579-82.

[4] JC van der Heide, M Hadders-Algra. Postural muscle dyscoordination in children with cerebral palsy. Neural Plast. 2005; 12(2-3):197-203.

[5] Y-P Chen, T-Yow Kang, J-L Doong, S-J Lee, M-W Tsai, S-F Jeng, W-H Sung. Use of virtual reality to improve upper-extremity control in children with cerebral palsy: A single-subject design research report. Phys Ther. 2007;87:1441-1457.

[6] E Dursun, N Dursun, D Alican. Effects of biofeedback treatment on gait in children with cerebral palsy. Disabil. Rehabil. 2004 Jan 21;26(2):116-20.

[7] GR Colborne, FV Wright, S Naumann. Feedback of stríceps surae EMG in gait in children with cerebral palsy. Arch Phys Rehabil. 1994 Jan; 75(1):40-5.

[8] BR Seeger, DJ Caudrey, JR Scholes. Biofeedback therapy to achieve symmetrical gait in hemiplegic cerebral palsied children. Arch Phys Rehabil. 1981 Aug; 62(8):364-8.

[9] BR Seeger, DJ Caudrey. Biofeedback therapy to achieve symmetrical gait in hemiplegic cerebral palsy: long-term efficacy. Arch Phys Rehabil. 1983 Apr; 64(4):160-2.

[10] A Ledebt, J Becher, J Kapper, RM Rozendaalr, R Bakker, IC Leenders, GJ Savelsbergh._Balance training with visual feedback_in children with hemiplegic cerebral palsy: effect on stance and gait. Motor Control. 2005 Oct; 9(4): 459-68.

[11] JP Martin. Locomotion and the basal ganglia. In Martin JP, ed. The basal ganglia and posture. London: Pitman medical, 1967: 20-35.

[12] JP Azulay, S Mesure, B Amblard., O Blin, I Sangla, J Pouget. Visual control of locomotion in Parkinson's disease. Brain. 1999;122 (Pt 1): 111-20.

[13] Y Baram. Walking on tiles. Neural Proc Lett, 1999;10:81-87.

[14] Y Baram. Closed-loop augmented reality apparatus, US Patent No., 6,734,834-B1 2004.

[15] Y Baram., J Aharon-Peretz, Y Simionotici, L Ron. Walking on virtual tiles, Neural Proc Lett, 2002;16:227-233.

[16] Y Baram, A Miller. Effects of virtual reality cues on gait in multiple sclerosis patients. Neurology 2006; 66:178-181.

[17] Y Baram, A Miller. Auditory feedback for improvement of gait in multiple sclerosis patients. J of the Neurol Sci 2007; 254: 90-94.