

Virtual Reality Cues for Improvement of Gait in Patients with Multiple Sclerosis

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Abstract

Objective: To study the effects of visual cues, provided through a portable visual-feedback virtual reality (VR) apparatus, on the walking abilities of patients with Multiple Sclerosis (MS). *Methods:* On-line (display-on) and residual short-term therapeutic effects on walking speed and stride length were measured in sixteen randomly selected patients with gait disturbances predominantly due to cerebellar ataxia. *Results:* Patients whose baseline walking speed (BWS) was below the median showed an average on-line improvement of 13.46% in their walking speed, while patients whose BWS was above the median improved their speed by 1.47%. The average short-term residual therapeutic improvement in walking speed was 24.49% in patients with BWS below the median, and 9.09% in patients with BWS above the median. Similar results were obtained for improvements in stride length. These results of improved functions in patients are particularly noteworthy when compared with the lack of change in healthy control subjects. *Conclusions:* Patients with MS showed improvement in walking abilities using VR visual-feedback cues.

Introduction

Gait disturbances in patients with multiple sclerosis (MS) may result from pyramidal syndrome (muscle weakness, spasticity), sensory (proprio-kinesthetic perception) disturbances, general fatigue, as well as incoordination due to cerebellar ataxia.¹ About eighty five percent of patients with MS develop gait problems.¹ Gait limitation results in mobility-related handicaps that can considerably limit the patients' activities of daily living, as well as their social interactions, and, therefore, have major impact on the patients, their families, and society.² To date, most studies on gait rehabilitation, whether by means of physiotherapy, occupational therapy, or pharmacological treatment, have focused on improvement of muscle strength and reduction of spasticity (such as pharmacological approaches using Baclofen).^{3,4,5,6} However, the issue of cerebellar ataxia has gained little scientific attention, resulting in relatively poor treatment options.

Recent research has focused on the search for gait assessment methods, in an attempt to lead to new approaches in intervention and rehabilitation. Typically, these studies consider gait in terms of time-distance measurements, i.e., speed and stride length, and observe their relation to muscle and joint movement analysis, muscular strength, and aerobic conditioning.^{7,8,9,10,11,12} Patients with ataxia often use visual cues to maintain balance, which is the basis for the Romberg test. The application of virtual reality (VR) technology for the purpose of medical diagnosis and treatment has become widespread in the recent decade. Among its uses in neurological rehabilitation is the development of motor assessment and training methods, using electromyographic, tactile (haptic), and visual cues.¹³ A potential

advantage of VR technology for the purpose of motor training is the capacity to provide the trainee with immediate performance feedback¹⁴.

It has been demonstrated that certain sensory stimuli improve the walking abilities of neurological patients with movement disorders. In particular, moving visual cues, which generate a perception of motion, were found to have a beneficial effect on gait in patients with Parkinson's disease (PD).^{15, 16} A study of the closed-loop effects of real-world visual cues on the regulation and stabilization of gait¹⁷ has led to the development of a virtual reality apparatus.¹⁸ The closed-loop design employs a sensory feedback system to incorporate the patient's body motions in the display. The use of this apparatus was found effective for gait improvement in patients with PD above and beyond the effects of the open-loop version.¹⁹ In the present study we employed an advanced version of this device to study the effects of visual feedback cues on gait in patients with MS.

Methods

Subjects

Sixteen randomly selected MS outpatients, seven men and nine women, diagnosed according to the Poser criteria²⁰ with gait disturbances predominantly due to cerebellar ataxia, participated in the study. Exclusion criteria: considerable visual deficit not compensated by correction, ocular movement dysfunction (egs. diplopia, nystagmus), and gait disturbances due to pronounced muscle weakness, spasticity, sensory ataxia, or considerable general fatigue. Disease-related disability was assessed using the Kurtzke expanded disability status scale (EDSS)²¹. In addition,

Clinical assesment included Cerebellar Functional System Score (CFSS) which grades cerebellar function due to MS on a five grades score, in which: 0 = normal cerebellar function; 1= abnormal signs without disability; 2= mild ataxia; 3= moderate ataxia; 4= sever ataxia in all limbs or trunk; 5= unable to perform coordinated movemenet due to ataxia.

Ambulation assessment

Assessment of patient ambulation, conducted by an impartial independent investigator, was carried out using the ambulation measurements of walking speed (meters/second) and stride length (meters), calculated directly from measurements of time and number of steps needed to complete a fixed track. The control group consisted of twelve healthy individuals. The study was approved by the institutional Helsinki committee and informed consent was obtained from each of the participants once the nature of the procedures had been fully explained. Clinical and personal data of patients and control groups are presented in Table (E) T-1.

Virtual Reality (VR) apparatus and mode of assessment

Visual cues were generated by a Virtual Reality apparatus¹⁸: a closed-loop head-mounted device, shown in Figure (E) F-1. The display, attached to the eyeglasses frame, provides the patient with a virtual tiled floor in a checkerboard arrangement, responding dynamically to the patient's own motion, much like a real floor, fixed in space.

Procedure

All tests were performed at the Multiple Sclerosis Center, Carmel Medical Center, Haifa, Israel, at about the same time in the morning. Examination of each patient comprised four stages, each consisting of the patient walking a straight track of 10

meters: baseline, online display off, online display on, and residual effects, as hereinafter:

Stage 1: Baseline walking speed and stride length, were measured first, without the device. The patient was verbally instructed to start walking. The time to complete the 10-meter track and the number of steps were recorded four times and averaged.

Stage 2: The device was placed on the patient, but it was not turned on. Walking speed and stride length were again measured four times and averaged. The purpose of this stage was to produce a reference for the effect of the visual cue alone, without the burdening effect of the device.

Stage 3: The display was turned on. The patient was instructed to walk on the virtual tiles along the 10-meter track. Walking speed and stride length were measured four times and averaged.

Stage 4: The device was taken off the patient, who was given a ten-minute break. After the break, the patient was 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 the visual cues.

Results

Clinical features, baseline measurements and On-line improvement

The test results for the patients and for the control subjects are summarized in Table (E) T-2. Baseline walking speed and stride length of patients before using the device is given first. Walking speed and stride length of patients wearing the device, with

the display turned off and on, are given in the “on-line” columns, along with percentage changes between “display off” and “display on”. Walking speed and stride length after the break, without the device, are given in the “residual effect” columns, along with percentage changes with respect to the baseline walking speed and stride length.

The percentage improvement in the on-line walking speed of the patients and of the controls with respect to the baseline walking speed is depicted for comparison in Figure 1. Similarly, the residual improvement of the two groups is depicted in Figure 2.

The medians of the baseline walking speed and stride length were 0.994 m/s and 0.527 m for the patients, and 1.379 m/s and 0.728 m for the controls.

For the MS patient group, the on-line walking speed improved, on average, 13.46% in patients below the median and 1.47% in patients above the median. Using the baseline walking speed (BWS) value of 0.7 m/s as a separation threshold, it was found that the on-line walking speed improved, on average, 20.32% in patients with BWS below the threshold and 1.63% in patients with BWS above the threshold .

On-line average improvement in stride length was 9.78% in patients below the median and 5.74% in patients above the median. Using the baseline stride length (BSL) value of 0.45 m as a separation threshold, it was found that the stride length improved, on average, 14.01% in patients with BSL below the threshold and 4.92% in patients with BSL above the threshold.

In contrast to the results for the patients, the results for the controls did not show any particular trend in relation to the baseline walking speed or stride length.

Furthermore, using the device did not improve performance, quite the contrary, due

to the burdening effect of wearing the device. Indeed, it was found that the on-line walking speed changed, on average, by -5.3% in controls below the median and by -6.36% in controls above the median of the BWS. As in the case of the walking speed, there was an on-line decrease in stride length as a function of the BSL in the controls. The on-line average change in the stride length was also negative, -2.36% in controls below the median BSL and -1.08% in controls above the median. This makes the results for the patients even more noteworthy, since improved apparatus and prolonged training are expected to reduce the burdening effect, hence, further improve performance.

Residual improvement

The residual improvement in the walking speed (Figure 2) was, on average, 24.49% in patients below the median BWS and 9.09% in patients above the median.

Average residual improvement in walking speed was 32.61% in patients with BWS below 0.7 m/s and 9.59% in patients with higher BWS. In contrast, there was no notable residual improvement in the walking speed of the controls (2.49% and 2.36% changes in controls below and above the median BWS). The residual improvement in stride length of the patients was 16.32% in patients below the median BSL and 4.86% in patients above the median. Average residual improvement in stride length was 21.36% in patients with BSL below the 0.45 m threshold and 5.69% in patients with higher BSL. On the other hand, the controls did not show any residual improvement in the stride length (0.08% and -0.74% changes in controls below and above the median BSL).

During the tests, most of the patients reported a new sense of confidence and awareness. Following the tests, patients reported that an image of the tiles remains in their mind. One of the patients called a week after the test, saying that, when she walks, she is still walking on the tiles in her mind. Another patient reported in her subsequent visit that she walked better the whole week following the test.

Discussion

The advantage of VR implementation in neurological rehabilitation is the ability to control and monitor the delivery of stimuli.¹⁴ Applying this principle, VR assisted methods of rehabilitation have been devised to assess and treat both cognitive deficits and motor disorders. A case in point is the use of VR to provide visual feedback cues to improve gait control in patients with PD. It has been suggested that the series of transverse lines may help trigger step transitions during walk in patients with PD¹⁵, and the stabilizing effect of such information has been shown¹⁷. Consequently, the delivery of a tiled floor pattern, responding dynamically to the patient's own motion, through a head-mounted VR device, has been suggested¹⁸. When aided by the VR device, the gait quality of the PD patients improved considerably¹⁹. The potential use of VR in the rehabilitation of patients with dysmetria, spasticity, and muscle weakness, using different stimuli, including haptics and EMG has been proposed recently¹³. The results of the present study clearly indicate that it is possible to use VR cues, superimposed on the real world in a closed-loop fashion, to help patients with MS control their gait. The degree of improvement, both on-line and residual, was found to be inversely related to the baseline walking speed and stride length. These improvements in performance seem

particularly noteworthy when compared to the results obtained for the controls, which showed no meaningful improvement. Above all, our findings regarding residual improvement are particularly encouraging: average short-term residual therapeutic improvement in walking speed was 24.49% in patients with baseline walking speed below the median and 9.09% in patients above the median.

The results of the present study support the potential role of VR-based strategies as rehabilitation modalities in MS, and substantiate their specific implementation in efforts to alleviate, improve, and restore mobility in patients with gait disturbances due to neurological disorders in general.

Future studies may explore the implications of these results in larger cohort of patients of various clinical sub-categories (such as patients with 'above-median walking speed' and 'below- median walking speed'). 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 VR-enhanced rehabilitation to long-term learning would have added importance in MS, characterized by damage of coordinated interneuronal networks leading to associated dysfunction. Additionally, due to injury of CNS reserves in MS, cerebral reorganization and plasticity may be limited²². VR-aided neurorehabilitation that can demonstrate long-term motor skill learning may also elucidate important issues related to the modulation of neuronal networks for better resource allocation, the potential for functional cerebral reorganization, and the notion of “interventional/ adaptive cerebra plasticity”, as part of neuro-rehabilitation²².

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Tables

Table (E) T-1: Clinical characteristics of the MS patient and the control group

MS Patient Group						Control Group		
Patient	Sex	Age	DD	EDSS	CFSS	Subject	Sex	Age
1	M	39	6	3	2	1	W	25
2	W	24	5	6	4	2	M	26
3	M	44	19	3.5	3	3	M	27
4	M	16	1	3	2	4	W	28
5	W	20	5	4.5	4	5	W	23
6	W	43	12	5	4	6	W	26
7	M	54	23	6	3	7	M	25
8	M	30	2	5.5	3	8	W	23
9	W	33	4	4	3	9	W	23
10	W	34	3	4.5	3	10	M	27
11	M	50	1	3.5	2	11	M	28
12	M	67	4	6.5	4	12	M	24
13	W	50	25	2	2			
14	W	48	6	5.5	4			
15	W	46	18	3.5	2			
16	W	47	3	5	3			

(DD=disease duration in years; EDSS =Expanded Disability Status Scale;

CFSS=Cerebellar Functional System Score)

Table (E) T-2: Test results for patients with MS and for control subjects: walking speed (meters/second), and stride length (meters)

Patient	Baseline Ambulation		On-line						Residual			
			Display Off		Display On		Percentage Change		After Break		Percentage Change	
	Walking Speed	Stride Length	Walking Speed	Stride Length	Walking Speed	Stride Length	Walking Speed	Stride Length	Walking Speed	Stride Length	Walking Speed	Stride Length
1	0.764	0.488	0.687	0.476	0.648	0.476	-5.68%	0.00%	0.785	0.526	2.75%	7.79%
2	1.093	0.555	1.107	0.555	1.005	0.625	-9.21%	12.61%	1.153	0.588	5.49%	5.95%
3	1.207	0.667	1.158	0.667	1.218	0.667	5.18%	0.00%	1.378	0.714	14.17%	7.05%
4	1.291	0.690	1.262	0.606	1.320	0.714	4.60%	17.82%	1.320	0.714	2.25%	3.48%
5	1.316	0.645	1.298	0.625	1.203	0.625	-7.32%	0.00%	1.440	0.667	9.42%	3.41%
6	1.276	0.625	1.248	0.625	1.238	0.645	-0.80%	3.20%	1.323	0.625	3.68%	0.00%
7	0.577	0.425	0.528	0.400	0.628	0.488	18.94%	22.00%	0.708	0.513	22.70%	20.71%
8	1.072	0.625	1.059	0.625	1.072	0.625	1.22%	0.00%	1.204	0.667	12.31%	6.72%
9	0.915	0.500	0.950	0.500	1.041	0.541	9.57%	8.20%	1.041	0.541	13.77%	8.20%
10	0.808	0.476	0.809	0.476	0.827	0.476	2.22%	0.00%	0.962	0.513	16.32%	7.77%
11	1.194	0.667	1.205	0.667	1.445	0.769	19.91%	15.29%	1.508	0.769	26.30%	15.29%
12	0.178	0.162	0.136	0.133	0.156	0.152	14.71%	14.29%	0.180	0.172	1.12%	6.17%
13	1.272	0.625	1.290	0.625	1.267	0.606	-1.78%	-3.04%	1.278	0.606	-0.93%	-3.04%
14	0.480	0.357	0.333	0.445	0.392	0.614	37.98%	17.72%	0.666	0.417	38.75%	16.81%
15	0.321	0.290	0.265	0.241	0.324	0.263	22.26%	9.13%	0.442	0.370	37.69%	42.31%
16	0.575	0.385	0.754	0.435	0.812	0.465	7.69%	6.90%	0.936	0.465	62.78%	20.78%

Control Subjects

1	1.627	0.741	1.553	0.714	1.496	0.769	-3.66%	7.69%	1.500	0.769	-7.80%	3.85%
2	1.371	0.769	1.290	0.769	1.196	0.741	-7.30%	-3.70%	1.350	0.769	-1.49%	0.00%
3	1.223	0.667	1.324	0.690	1.221	0.667	-7.75%	-3.33%	1.240	0.690	1.36%	3.45%
4	1.693	0.769	1.672	0.769	1.517	0.714	-9.26%	-7.14%	1.820	0.800	7.46%	4.00%
5	1.423	0.667	1.343	0.667	1.373	0.714	2.20%	7.14%	1.408	0.667	-1.06%	0.00%
6	1.260	0.769	1.322	0.769	1.183	0.714	-10.47%	-7.14%	1.358	0.769	7.74%	0.00%
7	1.316	0.769	1.322	0.769	1.255	0.769	-5.02%	0.00%	1.361	0.769	3.47%	0.00%
8	1.458	0.741	1.461	0.741	1.311	0.714	-10.29%	-3.57%	1.500	0.769	2.93%	3.85%
9	1.340	0.667	1.293	0.625	1.328	0.625	2.72%	0.00%	1.361	0.645	1.57%	-3.23%
10	1.430	0.714	1.537	0.769	1.409	0.714	-8.32%	-7.14%	1.631	0.769	14.11%	7.69%
11	1.422	0.714	1.397	0.714	1.273	0.690	-8.85%	-3.45%	1.333	0.667	-6.27%	-6.67%
12	0.868	0.625	0.876	0.625	0.842	0.625	-3.96%	0.00%	0.896	0.625	3.13%	0.00%

Figure Legends

Figure 1: On-line percentage improvement in the walking speed of patients with MS and of control subjects as a function of the baseline walking speed.

Figure 2: Residual (short term therapeutic) percentage improvement in the walking speed of patients with MS and of control subjects as a function of the baseline walking speed.

Figure (E) F-1

Visual-feedback virtual reality device used in tests





