Game-based Exercises for Dynamic Short-Sitting Balance Rehabilitation of People With Chronic Spinal Cord and Traumatic Brain Injuries

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Background and Purpose

Goal-oriented, task-specific training has been shown to improve function; however, it can be difficult to maintain patient interest. This report describes a rehabilitation protocol for the maintenance of balance in a short-sitting position following spinal cord and head injuries by use of a center-of-pressure–controlled video game–based tool. The scientific justification for the selected treatment is discussed.

Case Descriptions

Three adults were treated: 1 young adult with spina bifida (T10 and L1–L2), 1 middle-aged adult with complete paraplegia (complete lesion at T11–L1), and 1 middle-aged adult with traumatic brain injury. All patients used wheelchairs full-time.

Outcomes

The patients showed increased motivation to perform the game-based exercises and increased dynamic short-sitting balance.

Discussion

The patients exhibited increases in practice volume and attention span during training with the game-based tool. In addition, they demonstrated substantial improvements in dynamic balance control. These observations indicate that a video game–based exercise approach can have a substantial positive effect by improving dynamic short-sitting balance.

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Balance of the human body requires timely control of the position and motion of the center of body mass relative to the base of support. Maintaining balance in a short-sitting position at rest; during voluntary head, arm, and body movements; and during transfers and wheelchair use (both indoors and outdoors) involves many essential sensory and motor processes. Feedforward predictive controls, which initiate preparatory postural adjustments (goal-directed voluntary movements), are required to maintain balance during these movements and to anticipate potential future disturbances.[1] Sensory feedback processes are essential for responding in a timely fashion to unexpected disturbances or to correct for movement errors.

Restoration and maintenance of independent dynamic short-sitting balance* are priorities for many people who use wheelchairs because of a spinal cord lesion or an acquired or traumatic brain injury. As in standing posture, poor balance in a short-sitting position will increase the fear of falling, fall risk, and mobility limitations, creating greater patient dependency in basic and instrumental activities of daily living. Poor posture also can have an effect on a person's self-confidence in dealing with other people.[2] In turn, these issues can cause reduced levels of physical activity, participation in sports, and, more generally, quality of life.

Evidence from human studies shows that goal-oriented, task-specific training improves function and that increased amounts of training produce better outcomes[3–5] (for a complete review, see Kwakkel[6]). One problem with task-specific treatment approaches, however, is maintaining people's interest in performing repetitive tasks and ensuring that they complete the treatment program. A lack of interest or a short attention span also can impair the potential effectiveness of therapeutic exercises. Conversely, the use of rewarding activities has been shown to improve people's motivation to practice.[7–11] Various approaches have been put forth to couple motivating experiences with rehabilitation exercises. Biofeedback, in which a biological signal is recorded and presented to people, has long been used clinically to create and strengthen the awareness of a given task or performance.[12–16]

Novel and promising methods of applying biofeedback to rehabilitation are virtual reality and video games.[17–22] In a study by Webster et al,[23] a virtual environment was created to help people with the control and mobility of their wheelchairs, and participants had to navigate through a virtual obstacle course. After treatment, the participants exhibited a decrease in wheelchair accidents and falls and showed better performance on an actual obstacle course compared with subjects who did not have training with the virtual course. Video games were used by O'Connor et al[24] in an attempt to increase the physiologic responses of people using manual wheelchairs and to examine their effects on the motivation of the people to perform their exercises. The GAMEWheels system interfaced commercial video games with rollers, allowing stationary propulsion of the wheelchairs. The observations showed that 87% of the subjects found that the games motivated them to perform their exercises.

On the basis of these ideas and results, 3 interactive video game-based exercises that are controlled by use of center-of-pressure (COP) signal biofeedback were created. This interactive exercise tool has been applied to standing balance.[25,26] Betker et al[25] administered a questionnaire to 15 subjects (7 with balance disorders and 8 without balance disorders) after they played a 10-minute session of each game. The results were encouraging. The subjects indicated that the games were challenging and fun and would be a welcome addition to current treatment programs. Subsequently, Betker et al[26] reported on the feasibility and benefits of interactive standing balance exercises carried out with the COP-controlled video game system for 3 people who had chronic neurological deficits. The postexercise observations demonstrated that the people exhibited few falls, decreased COP excursion limits for some tasks, and increased attention span during training.

In our treatment program, COP-controlled video game-based exercises were used to attempt to improve dynamic short-sitting balance in people with central nervous system injuries. We thought that the inclusion of motivational and functional gaming in rehabilitation and sports training might increase the people's desire to perform their exercises and therefore result in improved dynamic balance control after the exercises.

Case Descriptions

Patient Histories

Three people consented to be treated and provided the following information.

Patient 1 was a 26-year-old man with spina bifida (myelomeningocele) extending from T10 to L1–L2 and resulting in complete paraplegia and poorly developed lower extremities. At the time of initial assessment, he demonstrated good static and dynamic short-sitting balance and was independent with all transfers, activ-

* Defined as maintaining an upright position of the torso while sitting on the buttocks or thighs (or both), with the shank hanging over the sitting surface.

ities of daily living, and work. As a person who participated in Paralympic sports, he actively raced for Team Canada and was actively training to improve dynamic balance control, an important requirement for high-speed wheelchair racing.

Patient 2 was a 52-year-old man with complete paraplegia (T11-L1) and a transfemoral amputation; these injuries resulted from a motor vehicle accident 10 months before recruitment into our treatment program. After the accident, he received inpatient rehabilitation for 6 months. At the time of initial assessment, before the current treatment program, he demonstrated complete motor and sensory loss below the T11 level, demonstrated dependent short-sitting balance (he sat with a kyphotic posture with bilateral upper-extremity support and was unable to perform any functional activity with the upper extremities in an unsupported short-sitting position), and required moderate assistance from one person for transfers. His primary treatment goal was to regain independent short-sitting balance for return to office work.

Patient 3 was a 41-year-old man who had had a severe traumatic brain injury more than 5 years before the current treatment program. He had received physical therapy intervention several times during those 5 years for trunk and lower-extremity motor control and balance reeducation. His upper-limb function was good bilaterally, but he had poor trunk and lower-limb motor control and high muscle tone (velocity-dependent resistance to stretch), which fluctuated from extensor tone to flexor tone, depending on his positioning. He had a progressive plantar-flexion contracture of the right ankle secondary to spasticity (hypertonity of the plantar flexors). He was unable to maintain short-sitting balance without the use of his hands for support because of impaired balance and trunk control. As a result (and because of his size), he had to be transferred with a Hoyer lift. He used a powered wheelchair for mobility indoors and outdoors. He had no sensory loss, and his intellectual and memory functions also were intact. However, he was easily distracted during most activities and therapy, requiring constant cuing and verbal commands to stay focused on the task at hand.

COP-Controlled Video Game–based Exercise Tool

The COP position signal has long been used as an indicator of balance performance.[27–30] We developed the COP-controlled video game-based exercise tool for use with the Force-Sensitive Applications (FSA) software[†] and pressure mat.[†] The COP position signal input is acquired via a flexible pressure mat measuring 53 × 53 × 0.036 cm and containing a 16 × 16 grid of piezoelectricity-resistive sensors spaced 2.8575 cm apart (other mat sizes are available). The flexibility of the pressure mat permits games to be performed on solid, fixed surfaces and allows progression to compliant surfaces, with the FSA pressure mat being placed between the patient and the surface. The position of the COP is calculated from the pressures produced by the patient seated on the pressure mat. This COP position signal then is mapped as an input to each of 3 different games (Under Pressure, Memory Match, and Balloon Burst), which are described below.

In Under Pressure (Fig. 1a), game players shift their weight to move a receptacle in order to “catch” an object. The game comprises 3 modes: in the horizontal mode, players must shift their weight side to side; in the vertical mode, players must shift their weight back and forth; and in both modes together, players must shift their weight in all directions. Thus, movement range and speed in all or targeted directions are exercised. Difficulty levels can be configured through the receptacle size, the object speed, the number of objects, and the option of multiple objects appearing at specified intervals.

In Memory Match (Fig. 1b), the goal is to select 2 matching cards from a 3 × 3 or 4 × 4 array of squares. Game players select a card (square) by shifting their weight to move the on-screen COP indicator to 1 of the 9 or 16 possible cards (squares). Once the COP is held still in a square for a duration selected by the player, the card is revealed. The second card then is selected in a similar manner; if the cards match, they remain face up. This process is repeated until all of the card pairs are selected. Difficulty levels can be configured through the number of seconds the players have to select their cards and the number of cards displayed (9 or 16).

In Balloon Burst (Fig. 1c), a newly created game, the goal is to “pop” balloons. Stationary balloons appear at random locations on the screen. Game players must shift their weight in all directions in order to move the on-screen COP marker over the balloon to pop it. The difficulty level can be configured through the size of the balloon.

In order to allow a customized and graded protocol for each player, the interactive video game system offered the following features. The adjustable difficulty levels within the game software helped to ensure that each player was competitive and could successfully play the video games while exercising his full range and speed of voluntary movement. This feature is important to prevent a player from becoming frustrated and

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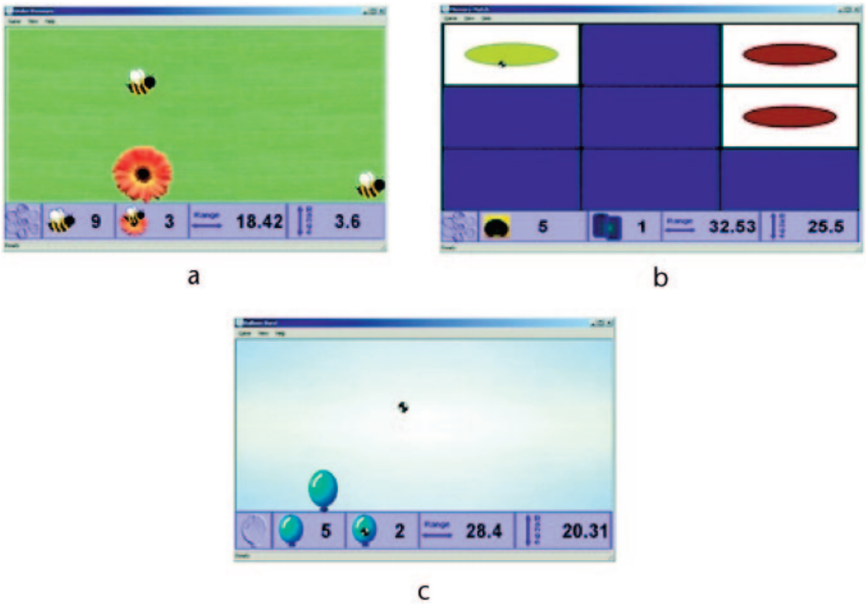

Figure 1.
Screenshots of games. (a) Under Pressure during horizontal mode. The game player must move the flower under the bee. The total number of bees, the number of bees caught, and mediolateral (ML) and anteroposterior (AP) movement ranges (in centimeters) are displayed. (b) Memory Match. The game player must select cards in order to find the pairs. The number of pairs found and the ML and AP movement ranges (in centimeters) are displayed. (c) Balloon Burst. The game player must move the cursor over the balloon to pop it. The total number of balloons, the number of balloons popped, and the ML and AP movement ranges (in centimeters) are displayed.

quickly losing interest. The game software allows the player's movement range to be determined dynamically or manually and can be scaled, allowing even people who are severely disabled to play and be competitive.

Evaluations and Outcome Measures

Two different test protocols were used to obtain quantitative outcome measurements: (1) a questionnaire that was administered after the exercises and (2) stability measurements that were obtained during a set of 6 tasks performed under 2 conditions (before and after exercise). The 2 protocols are described below.

Questionnaire. After exercise, a questionnaire that included the following questions was administered: Were the video game-based exercises fun to play? Did the video games increase your motivation to perform your exercises? Were the video game-based exercises challenging? Did the difficulty levels of the video games enhance the exercises? and Do you prefer video game-based balance exercises to traditional balance exercises? The response options were: "strongly disagree," "disagree," "agree," and "strongly agree."

Dynamic balance assessment. In keeping with the Sensory Organization Test concept, Shumway-Cook and Horak[31] devised a clinical tool for testing the sensory component of balance: the Clinical Test of Sensory Interaction and Balance. In the Clinical Test of Sensory Interaction and Balance, a compliant foam pad is used as an unstable support base to simulate the Sensory Organization Test in terms of somatosensory distortion, with an added advantage that it is not limited to the pitch plane; the disturbance can be multidirectional.[32] For the purpose of our treatment program, an air bladder was used to distort and produce an unstable support surface, in a manner similar to the compliant foam pad used during standing. The air bladder modified the surface reaction forces under the seat; thus, the surface could not completely reciprocate the normal forces beneath the seat as the center of body mass moved. The result was an increase in the magnitude and frequency of involuntary (unpredictable) body sway. To prevent a loss of balance, a fall, or both, an individual must be able to sense and respond to this condition. This condition constitutes a demand on whole-body balance reactions, and continuous automatic postural adjustments are required to maintain upright short-sitting balance and postural stability. The degree of difficulty of the balance tasks could be adjusted by se-

Table 1.
Task Descriptions

Task	Description
1	Maintain erect short-sitting balance with eyes open and looking straight ahead, as part of the CTSIB.[a]
2	Maintain erect short-sitting balance with eyes closed, as part of the CTSIB.
3	Perform rhythmic left and right horizontal head rotations to visual targets placed 120° apart.
4	Perform a rhythmic arm lifting and lowering task while holding a 50-cm lightweight wooden pole, 1.91 cm in diameter, with the hands kept shoulder width apart. Raise the pole to eye level and then back down to the legs, keeping elbows extended.
5	Perform rhythmic left and right horizontal trunk rotations to approximately 30° in each direction.
6	Perform rhythmic forward trunk bending and extension to return to the upright (erect) short-sitting position. The amplitude of trunk flexion should be approximately 30°.

[a] CTSIB=Clinical Test of Sensory Interaction and Balance.

lecting different shapes and sizes for the air bladder, just as different thicknesses and densities could be selected for the foam pad used during standing.

A SwisDisk[‡] was used for patients 2 and 3, and a deflated (80%–90% of the air removed) yellow Physio Gymnic[§] ball (a more difficult and unstable surface) was used to challenge patient 1. Patients were transferred from their wheelchairs to a low treatment plinth for all testing. To minimize any skin irritation during testing (and treatment), the patients were seated on their regular seat cushions (foam-type cushions designed to help distribute forces evenly, away from bony prominences, thus reducing the risk of ulceration). Each patient was instructed to perform 6 tasks (Tab. 1), each 20 seconds in duration, under 2 different conditions: first while sitting on their regular seat cushions and then while sitting on the air bladders. Hand support was not permitted for this test.

[‡] PI Professional Therapy Products Inc, PO Box 1067, Athens, TN 37371.

[§] Ledraplastic Spa, Via Brigata Re 1, Osoppo, Udine, Italy 33010.

The 4 movements (tasks 3–6) were paced by the beat of a metronome, set to a frequency of 0.4 Hz. These movements were selected because they represent important functional activities of daily living and work. The metronome frequency was selected to represent relatively slow self-paced movement speeds. For all 6 tasks and both surfaces (cushion and air bladder), a fall was recorded if the patients could not maintain independent balance for 20 seconds or if they could not perform the movements without holding on with their hands. A physical therapist was positioned directly behind the patients to provide assistance, if needed.

Intervention

All treatments were performed at an outpatient physical therapy clinic operated by the Division of Physical Therapy, School of Medical Rehabilitation, University of Manitoba; the program was designed partially for the clinical training of undergraduate physical therapist students under supervision. Each patient attended twelve 30- to 45-minute exercise sessions 2 or 3 times per week. The exercise regimen consisted solely of our COP-controlled video game-based exercises; the patients did not receive any other balance training or physical therapy intervention during the treatment period. The patients were transferred from their wheelchairs to a low treatment plinth for all treatments.

Patient 1 played Under Pressure in all modes only. Patient 2 played Under Pressure 80% of the time, played Memory Match 19% of the time, and tried the new game, Balloon Burst, for the remaining 1% of the time. Patient 3 played Under Pressure 70% of the time and Memory Match for the remainder of the time. The games were played with the patients sitting on the treatment plinth and progressed (as appropriate) to sitting on a deflated Physio Gynmic ball or SwisDisk; the FSA pressure mat was placed between the patient and the surface (Fig. 2). The ball or disk added uncertainty to the system, as it would randomly modify the surface reaction forces; for people with sensation, it would distort or delay the pressure information from seat-to-surface contact.

As improvements in game play scores were noted and as improve-

Figure 2.
System setup. The patient sits on the pressure mat (1), which is connected to the laptop by the interface box (2). The laptop currently displays the game Balloon Burst. The pressure mat is currently placed on top of the SwisDisk (3); the Physio Gymnic (4) ball also is depicted.

ments in balance and head-arm-trunk control were observed, the treatment program progressed. In general, the minimum game play score was set at 50% success—for example, catching the object 50% of the time in Under Pressure.

There were a number of game parameters and task conditions that could be adjusted and modified when appropriate in order to permit the treatment program to progress and to challenge the patients. These included the following 5 items:

1. A scaling factor was used to map the magnitude of COP excursion (movement range) to the excursion of the game cursor on the computer display. Initially, the program was set so that a relatively small COP excursion produced a moderate to large game cursor movement. As game play scores improved and as balance or trunk control improved, scaling was increased so that larger and larger COP excursions were required to move the game cursor.

2. The speed of the game targets (objects) was adjusted. Initially, the speed was set to slow; this setting permitted more time for the patients to move and position the game cursor (COP) to catch the object. Increasing the game speed required faster COP movement. Alternately, very slow speeds required the patients to hold the COP position at the desired locations for longer periods of time. For example, when a lateral or anterior trunk tilt was required to catch the object at a very slow target speed, the patient would have to hold the tilted position for a few seconds. Game speed was adjusted, scaling was adjusted, or both as game play scores improved and as balance improved.

3. The exercise interval was increased by increasing the number of game targets, that is, the number of objects. Initially, the interval duration was set to be-

tween 15 and 30 seconds of game play. As tolerated, this duration was increased to 60 to 90 seconds in order to increase the number of repetitions and to build endurance.

4. Reliance on hand support for balance progressed to less reliance, from using both hands to using one hand and then using no hand support.

5. Air bladders were used to introduce a destabilizing compliant support surface. Once the patients were able to play the games without hand support, a compliant support surface was introduced. By changing the amount of air in the Physio Gymnic ball or SwisDisk, an appropriate training level was achieved and progress was made. For patients 2 and 3, within 3 treatment sessions, air bladders were being used for the entire treatment session. For patient 1, an air bladder was used immediately, as this type of support surface was required to challenge his balance control.

Outcomes

Questionnaire

The questionnaire results were very positive, with all patients answering "strongly agree" to all 5 questions. All of the patients indicated that they enjoyed the video game-based tool, preferring it over exercise programs that they had performed in the past, and indicated that they would like to continue the treatment. The adjustable parameters and different modes of the tool offered sufficient difficulty levels; even patient 1, who participated in Paralympic sports, found the games to be challenging. In addition, patient 2 particularly enjoyed the new game, Balloon Burst, preferring it over the other games.

Dynamic Balance Assessment

The results of the dynamic balance assessment are shown in Table 2.

Before exercise, patient 1 maintained independent short-sitting balance for the full 20 seconds during all 6 tasks when he sat on his regular wheelchair cushion; in addition, short-sitting balance was maintained for the eyes-open, head rotation, and arm lifting tasks when he sat on the deflated Physio Gymnic ball. However, for 3 other conditions, when patient 1 sat on the deflated Physio Gymnic ball, he clearly lost short-sitting balance, and therapist intervention was required to prevent a fall. After exercise, patient 1 maintained independent short-sitting balance for the full 20 seconds during all 6 tasks on both surfaces.

For patient 2, 9 falls were recorded before exercise. Patient 2 was able to maintain independent short-sitting balance (without the use of his hands for support) only while sitting on the wheelchair cushion in the eyes-open, head rotation, and arm lifting tasks. After exercise, patient 2 was able to maintain independent short-sitting balance for the full 20 seconds during all tasks on both surfaces (cushion and disk).

Before training with the COP-controlled video game-based system, patient 3 typically would attend only to balance exercises for 20 to 30 seconds at a time, with the training sessions typically lasting for only 10 to 15 minutes. After practice with the COP-controlled video game-based system, patient 3 was able to maintain concentration during the games (balance exercises) for up to 2 to 3 minutes at a time and would repeat this activity 10 to 15 times. The duration of the exercises increased from short-interval training (approximately 20 seconds for 10–15 minutes) to 2-minute interval training for 20 to 30 minutes. Twelve falls were recorded before exercise for patient 3. In addition, hand support was required during all 6 tasks on both surfaces (cushion and disk). After exercise, patient 3 was able to maintain independent short-sitting balance for 20 seconds during all tasks on both surfaces.

Discussion

Here we report on the feasibility and benefits of interactive COP-controlled video game-based exercises for short-sitting balance rehabilitation. Our observations demonstrate that improved rehabilitative interventions, which incorporate a functional approach to training and graded balance conditions or disturbances (ie, sensory feedback and increased muscle activity), can produce substantial improvements in dynamic short-sitting balance. Complete spinal cord lesions below T10, T11, or T12 will abolish proprioceptive and cutaneous or pressure sensation in the hip joints and in the pelvis structures and thereby will reduce the available spatial information, which is needed to maintain short-sitting balance in the unsupported upright position. This effect is amplified without vision—that is, in dark or low-light conditions—and during sitting on different compliant surfaces. Learning a new balance sense is an important objective during rehabilitation for people with complete thoracic spinal cord lesions and traumatic brain injuries. Functionally, during game play, interactive movements are random, varying in direction, amplitude, and precision; thus, during game play, people need to make slow, maintained goal-directed movements or quick shifts in the COP trajectory. At moderate to high target (object) speed settings, these body movements require active mediolateral and anteroposterior weight shifts—for example, acceleration of the center of mass toward the intended target, followed quickly by body deceleration to stop the movement.

Table 2.
Dynamic Balance Assessment Results[a]

Surface	Task	Result for:					
		Patient 1		Patient 2		Patient 3	
		Before Exercise	After Exercise	Before Exercise	After Exercise	Before Exercise	After Exercise
Cushion	1	—	—	—	—	Fall	—
	2	—	—	Fall	—	Fall	—
	3	—	—	—	—	Fall	—
	4	—	—	—	—	Fall	—
	5	—	—	Fall	—	Fall	—
	6	—	—	Fall	—	Fall	—
Air bladder	1	—	—	Fall	—	Fall	—
	2	Fall	—	Fall	—	Fall	—
	3	—	—	Fall	—	Fall	—
	4	—	—	Fall	—	Fall	—
	5	Fall	—	Fall	—	Fall	—
	6	Fall	—	Fall	—	Fall	—

[a] Dashes indicate that no fall occurred.

The interactive gaming activities (exercises) were designed around a flexible pressure mat for COP recording. This method allows training to be conducted on compliant or uneven surfaces; that is, the mat may be placed on top of a compliant or irregular surface rather than on a force platform. The ability to apply a graded compliant support surface, along with the adjustable parameters of the tool, offers a variety of difficulty levels. For example, a deflated Physio Gymnic ball was required to challenge the balance of patient 1, who is active in wheelchair racing and team sports. Similarly, a Swis-Disk was used to increase the balance requirements of the exercises for patients 2 and 3. Thus, each game and session could be enhanced to meet the needs and performance levels of each patient. Such flexibility can better prepare people to interact and deal with more dynamic environmental conditions. Flexible pressure mats permit accurate COP recording while eliminating the nonlinear distortions and damping effects produced in the COP trajectory by different materials.[33]

A main observation in this case report was that the interactive gaming intervention can motivate people with chronic spinal cord and traumatic brain injuries to practice dynamic movement tasks. This approach was applied effectively to people with severe balance and mobility limitations and to an individual who actively participated in sports. All 3 people indicated that they enjoyed the video game-based tool, preferring it to normal treatment regimens, and that they would like to continue the treatment. These observations showed that our COP-controlled video game system provided a motivational and challenging environment. It has been shown that with the proper experiences and volume of practice, the spinal cord can establish new neuronal associations and demonstrate functional improvements.[34,35] One limitation of our treatment program is the potentially biased language in the questionnaire. In future treatment programs, the questions used to quantify the level of motivation or fun during a particular therapy program will be neutral in order to not lead or bias an individual's responses.

Another observation was that after exercise, all patients exhibited decreased fall rates. In particular, after exercise, patients 2 and 3 were able to maintain independent short-sitting balance while performing many demanding functional tasks. This observation is consistent with the observation that intense practice of a motor task following a complete spinal cord lesion can result in substantial functional improvements.

During game play, voluntary movements were generated in multiple directions and were varied in amplitude and speed. The patients produced accurate targeted movements, were competitive at least 50% of the time, and did not fall. It was evident that there was a temporary loss of balance and unwanted movements (because of poor sensory control, motor control, or both and the effect of the compliant support surface); however, corrective balance reactions were generated successfully. Thus, both goal-directed voluntary movements (feedforward control) and corrective balance reactions (feedback control) were evident during game play.

Like current biofeedback and virtual reality systems, the interactive video game system provided the patients and the therapist with instantaneous feedback about performance and goal attainment on a moment-to-moment basis. The patients and the therapist were able to measure their successful progression to more complex tasks and support surfaces in real time. Performance also could be logged on a trial-by-trial basis by use of the report feature. In future treatment programs, the functionality of the report feature of the video game system will be expanded to include additional outcome measures detailing a patient's performance.

Further motivation might be achieved through the development of a universal input device to allow the pressure mat to be used with commercial video games. This modification will increase the selection of games (an important factor in keeping players motivated and interested) and eliminate the cost of having to program new games. Masked, randomized clinical trials also are required to confirm these preliminary observations and to provide a comparison of the effects of this treatment with the effects of other, conventional therapies in parallel groups of patients.

Conclusions

Here we report on the benefits of our video game-based exercise regimen. Our observations demonstrated that graded, dynamic balance exercises on different surfaces can be coupled effectively with video game play and that this treatment offers the following values for rehabilitation: goal-directed and intended behavior with random target presentation and motion; the ability to map small to large active COP excursions to game cursor excursion on the computer display; the choice of a wide range of game speeds and thus movement speeds; the ability to select accuracy from small to large target (object) sizes; multitasking (incorporation of gaze control [head and smooth pursuit], attention to game play strategy [target motion and prediction of final location], body movements, and balance control); and rewards, with moment-to-moment feedback about goal attainment and positive reinforcement, both visual and audio. In addition to the training program being enjoyable, all 3 patients showed decreased fall rates after the video game-based exercise therapy. The portability of the system affords its use in monitored at-home programs, a feature that makes this therapy approach cost-effective.

Ms Betker, Mr Desai, and Dr Szturm provided concept/idea/project design and writing. Mr Desai, Ms Nett, and Ms Kapadia provided data collection. Ms Betker, Mr Desai, and Ms Kapadia provided data analysis. Ms Betker and Dr Szturm provided project management and facilities/equipment. Ms Nett and Dr Szturm provided patients. Dr Szturm provided institutional liaisons. All authors provided consultation (including review of manuscript before submission).

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